ACCOUSTICAL AND MASS PHYSICAL PROPERTIES OF DEEP OCEAN RECENT MARINE SEDIMENTS

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THESIS

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of
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ABSTRACT

Eight cores obtained from the Monterey Submarine Fan in the Pacific Ocean 50 to 75 miles off Monterey, California, were sectioned to conduct vane shear, compressional wave speed, and viscoelastic measurements. After the cores were sectioned aboard ship utilizing a heated element technique, core sections were immediately subjected to vane shear measurements utilizing a Wykeham-Farrance Vane Shear Machine modified to produce a graphical display of torque versus angle of blade rotation. Compressional wave speed measurements were also made aboard ship. Wet density, water content, porosity, and grain size distribution of sediment from core sections were determined later in the laboratory.

The relationship of sediment shear strength to mass physical properties and compressional wave speed is discussed. No correlations were apparent between shear strength of the sediment and any single mass physical property or the compressional wave speed of the sediment. A critical discussion of the vane shear test is presented with recommendations for test improvement.

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I. INTRODUCTION

The purpose of the research described in this report is to establish correlations between mass physical properties and acoustic properties of deep ocean sediments. The motivation for this research is the necessity for increased knowledge of acoustic characteristics of the ocean floor in order to improve the capability for prediction of ocean floor acoustic reflection and absorption when employing modern sonar techniques. By establishing relationships between mechanical (or mass physical properties) and acoustic properties, it is anticipated that it will be possible to calculate acoustic properties by utilizing mass physical parameters which are relatively easy to measure. Hamilton (1969a) and Cernock (1970) have investigated correlations between mass physical properties and acoustic properties in deep ocean sediments; their efforts have yielded promising results. Hamilton et al. (1969) have also employed a viscoelastic model of the ocean floor to more accurately describe acoustic bottom loss and reflectivity. At the U. S. Naval Postgraduate School (NPS), Cohen (1968), Bieda (1970), and Wilson and Andrews (1971) have made measurements to support a viscoelastic model describing deep ocean sediments. To accomplish the objective of establishing correlations between mass physical properties and acoustic properties of ocean sediments, samples obtained by coring operations were subjected to analysis to determine and compare mass physical, acoustic, and viscoelastic parameters.

The mass physical properties measured are wet density, water content, and shear strength as measured by a modified Wykeham-Farrance Vane Shear Machine. Additionally, grain size analysis data is presented for sediment samples. For the research described in this report, the vane shear data is considered to possess the greatest potential of all measured mass physical properties in the establishment of correlations with visco-elastic parameters. The vane shear test is one of five accepted means of determining static shear strength. In addition to previous utilization of the vane shear at NPS, other investigators in the field of marine sediments have made vane shear measurements. Moore (1964) subjected samples obtained from Project Mohole to laboratory vane shear measurements; additionally, Moore related sediment vane shear strength to cohesion, pore water pressure, and forces normal to the eventual plane of failure. Laboratory and in situ vane shear testing has been conducted at the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, California (Demars and Taylor, 1971). Vey and Nelson (1968) have evaluated the effects of environmental pressure on vane shear tests conducted for NCEL. At Texas A&M University, Bryant and Delflache (1971) and Cernock (1970) have employed the vane shear for research dealing with properties of sediment in the Gulf of Mexico. Inderbitzen and Simpson (1969) have compared the results of laboratory vane shear tests on marine sediments to results obtained from direct shear tests. Basically, the vane shear method is widely used, even though it is at times not completely understood.

It is emphasized that the measured mass physical properties including vane shear measurements are relatively easy to obtain utilizing equipment that is relatively uncomplicated and inexpensive. If these measurements can roughly indicate the acoustic properties of deep ocean sediments, then a means has been achieved to simply and inexpensively estimate sediment properties. Furthermore, it is anticipated that these correlations will further the overall understanding of the nature of deep ocean sediments for not only acoustic applications, but engineering applications as well.

To obtain sediment samples, the USNS BARTLETT (T-AGOR-13) was employed for a period of about 3 days from 10 May to 13 May 1972. Gravity coring was performed in an area approximately 60 miles off the coast of Monterey, California. On board ship, vane shear measurements and compressional wave speed measurements were made on selected sections of eight cores. Other sections were stored for transport to the NPS where other mass physical measurements were made. The following sections describe shipboard and laboratory procedures, presentation of data, discussion and conclusions, summary and recommendations.

II. PROCEDURES

A. SHIPBOARD PHASE

1. Coring Operations

Coring operations were conducted aboard USNS BARTLETT (T-AGOR-13) on 11 - 13 May 1972 in an area illustrated in Figure 1. The area was chosen so as to insure that samples would contain minimal amounts of sand-sized particles. The area is on the Monterey Submarine Fan; previous coring and dredging in this area has yielded samples which have a low sand content (Wilde, 1965). Minimization of sand content was necessary to insure the validity of viscoelastic data. The visco-elastometer (described by Bieda, 1970) which measures viscoelastic parameters gives reasonable results only for clays and silty clays and not for sandy sediments.

Samples obtained were gravity cores. The coring apparatus consisted of a 10-ft steel barrel, six 50-lb weights, and 2 3/8-inch diameter (inside) plastic core liners. The ship's hydro winch was used for each drop. The coring apparatus was allowed to free fall the final 300 m into the ocean floor. A total of eight cores were taken for the purpose of supporting the research described in this report. Immediately upon being brought aboard, cores were capped and then sectioned. Sectioning was performed with the heated element sectioning technique described by Smith (1963) which utilizes a soldering gun with a modified tip and positioning rings. The technique was evaluated as a successful

means of cutting core liners with a minimum distrubance to the contained sediment. After the core liner was cut, the sediment was cut by drawing a very thin stainless steel wire through it. Although the heated element technique is considered to be an acceptable procedure, some difficulty was encountered when sediments were of a fluid consistency with a high water content. Escape of water from these fluid sediments when the core liner was cut resulted in cooling of the core liner, thereby slowing cutting progress. Loss of water also resulted in sediment drainage. Additionally, fluid samples had a tendency to heal after they were cut with the stainless steel wire. The difficulty with fluid sediments was, however, encountered with only the top sections of four cores. Cutting further down these cores proceeded with no difficulty. Consequently, sectioning difficulty did not occur often enough to discourage use of the heated element method. With regard to dimensions, cores were cut into alternating 6-inch and 14-inch sections as illustrated in Figure 2. Section dimensions were selected to optimize the measurement of mass physical and viscoelastic properties. Core sections requiring storage were stored upright in the ship's refrigerator to minimize bacterial growth.

2. <u>Vane Shear Measurements</u>

Vane shear measurements were performed in the ship's dry laboratory space as soon as possible after the cores were sectioned. For measurements, the Wykeham-Farrance Vane Shear Machine with modifications was selected. The major modification to the basic machine is the installation of torque and rotation transducers to provide a continuous

readout of torque vs. angle of vane rotation. An additional modification is a motor mounted on the back of the vane shear machine to drive the vane rotation handle by means of a belt. The motorized drive provides smoother operation than manual turning; the motor drives the vane at a rate of approximately 20°/min. In addition to the vane shear machine with its attached torque and rotation transducers, the following system components are required: a DC power supply to provide rotation transducer excitation, a second DC power supply to provide torque transducer excitation, bridge balance circuitry (contained in a metal box), and an X-Y recorder to provide a graphic continuous record of the output of the torque and rotation transducers. A block diagram of the system is presented in Figure 3. The torque and rotation transducers were purchased from Diversified Marine Corporation of San Diego, California.

In order to gain operational experience with the vane shear equipment, the entire system was first completely checked in the laboratory using core sections obtained from previous oceanographic cruises. This laboratory familiarization phase also provided a sufficient opportunity to develop expertise in the core sectioning method previously described. Subsequent equipment checks included a shipboard evaluation conducted on the R/V ACANIA of NPS. Following these preliminary checks and evaluations, it was decided that the vane shear equipment was easily transportable and compatible with a shipboard environment. Although ship motion, primarily rolling due to wave conditions did cause some disturbance of the vane shear graphs on the X-Y recorder, [illegible] ng

of the ship to minimize motion prevented rolling of the ship from causing significant disturbance of the vane shear measuring system output.

The vane shear measurements conducted aboard USNS BARTLETT were made on the sediment contained in the 6-inch core sections cut from each core. Performing vane shear measurements on these sections enabled vane shear data to be obtained approximately every 20 inches down the core. The 20-inch interval resulted from the alternating 6-inch and 14-inch sectioning of the cores. A 6-inch length was selected for sections to be subjected to vane shear measurements to insure that the cut surfaces of each section were sufficiently displaced from the point within the core at which the vane shear measurement was actually taken. Correspondingly, 14-inch sections allowed for insertion of the probe of the viscoelastometer in relatively undisturbed sediment. (Viscoelastic measurements in the laboratory are now being conducted.) The 6-inch sections were placed in a clamp held securely to the base of the Wykeham-Farrance device. For all vane shear tests, a blade of two, 0.75-inch x 0.75-inch pieces of stainless steel joined at right angles was used. The vane was lowered into the clamped core sediment section to a depth of 2 inches. Energizing the motor on the vane shear device caused rotation of the vane which produced the recorded outputs of torque and rotation. Output graphs of torque versus blade rotation are presented and described in a subsequent section of this report.

3. Preparation of Samples for Porosity Determination

After the vane shear test was completed on a sample

1-inch long section of 1 inch diameter thin wall stainless steel tubing was slowly pressed into an undisturbed area of the sample to obtain a portion of the sample for water content and wet density measurements. This procedure was in actuality a small scale coring operation. Two of these samples were taken from each sample and then sealed in a plastic bag. Additional sample material was collected from inside the sample core liners for grain size analysis. This material was also placed in plastic bags. Bags containing sample material and 14-inch core sections were then stored under refrigeration at a temperature of about 5°C.

4. Measurement of Sound Speed

Compressional wave speed was measured in all 14-inch core sections and in all sections of Core Eight. A sediment velocimeter obtained from the Pacific Support Group of the Naval Oceanographic Office was used for these measurements. The velocimeter basically measures a time delay between sound transmission (at 400 KHZ) and reception between two transducers. The transducers are mounted so as to enable a core section containing sediment to be placed between them; the time delay measurement is made with the core liner in this position. To compensate for the effect of the plastic core liner on the time delay measurement, the computation of the velocity in the sediment involves a step which subtracts the time required for sound travel through the walls of the core liner. This is accomplished by comparing the time through the sediment filled core liner to the time delay through an identical core liner filled with distilled water. The distilled wa

temperature must be at approximately the same temperature of the sediment when measurements are made. Laboratory values of compressional wave speed were converted to in situ values by employing a technique determined by Hamilton (1969b). This technique is based on the observation that the ratio of water sound speed to sediment sound speed measured under laboratory conditions is equal to the same ratio in situ. Bottom water temperatures were obtained by either a Nansen or STDV cast at each station.

B. LABORATORY PHASE OF MEASUREMENTS

1. Storage of Samples

Upon completion of the coring cruise, samples were returned to the laboratory for storage. Fourteen-inch cores destined for visco-elastometer measurements were stored immersed in salt water at a temperature of 5°C. Sample material in plastic bags was stored in a refrigerator at the same temperature.

2. Density and Porosity Determination

Laboratory measurements of wet density and water content were conducted simultaneously using prescribed procedures (Lambe, 1957). After being removed from storage, each sediment-filled stainless steel tube section was carefully trimmed to remove all sediment which was not enclosed within the confines of the tube section. This insured that a measurable volume of sediment could be obtained by calculating the volume of the tube section. Each sample was then transferred from

within the tube section to a pre-weighed aluminum specimen dish. The wet sediment and dish were weighed and immediately transferred to a drying oven maintained at a temperature of 105°C. Samples were dried for a period of 24 hours, and then the dessicated sample and dish were reweighed. Two samples from each 6-inch core section were subjected to these measurements to increase data reliability by averaging results. The procedures just described made available all parameters necessary to calculate wet density and water content. Relationships for calculating the wet density and water content are as follows (Lambe, 1957):

$$\rho_w = \frac{W_1 - W_c}{V}, \qquad (1)$$

where

ρ_w = wet density,

W_1 = weight of specimen dish plus moist sample,

W_c = weight of specimen dish, and

V = volume of stainless steel tube section;

and

$$W = \frac{W_1 - W_2}{W_2 - W_c}, \qquad (2)$$

where

W = water content and

W_2 = weight of specimen dish plus dried sample.

Hamilton (1969) states that laboratory values of wet density differ from in situ values by a small amount which is probably insignificant an

within the margin of error of the measurement. In addition to wet density and water content, porosity was calculated. Porosity is considered to have an influence on acoustic and elastic properties of marine sediments. Hamilton (1969b) presents a relatively simple procedure by which this important sediment property can be calculated. Basically, porosity is the ratio of void volume to total volume. Hamilton's procedure involves the conversion of oven-evaporated water weight to volume (1 g of water occupies 1 cm^3 of volume). The assumption is made that the sediment is saturated, and consequently all voids are completely water filled. Therefore laboratory porosity is numerically equal to the weight of evaporated water divided by the volume of the saturated sediment. This ratio is expressed in per cent. Taking into consideration that evaporation leaves a residue of dried salts, it is necessary to make a small correction to obtain a salt-free sediment porosity. This correction takes the form of a multiplier which is equal to 1.01195 for the encountered bottom water salinity of 34.69‰.

3. Grain Size Analysis

All sediment samples were subjected to grain size analysis. The sieve analysis method was performed on the coarse fraction of each sample ($< 4\ \emptyset$), and the pipette method was used for each sample after the coarse fraction had been removed. Prior to separating the coarse fractions all samples were washed to remove entrapped salt water. Washing was accomplished by mechanically mixing the sediment with water, pouring the water-sediment mixture into a container, allo...

the sediment to settle to the bottom of the container (1 week required), and finally decanting the wash water from the container. After each sample was washed once with tap water, it was mixed with distilled water and allowed to settle for 1 week. When all samples had settled, flocculation was observed in each sample. One tenth of a gram of deflocculant (Calgon) was added to each of the samples; vigorous shaking insured that the deflocculant was mixed throughout the water-sediment mixture.

Following a settling period of 1 week, samples were shaken vigorously, and then the water-sediment mixture was poured through a 4-Ø sieve to accomplish separation of the course fraction. The coarse fraction was then oven-dried and a standard sieve analysis was performed in 0.5-Ø increments. The fine fraction plus water was placed in settling tubes, and a standard pipette analysis was performed in 0.5-Ø increments. Prior to commencing the pipette analysis, all samples required further deflocculation. Half of the samples were deflocculated successfully with an additional 0.2 g of deflocculant per 1000 ml of suspended sample; other samples required the addition of 0.4 g of deflocculant.

4. Viscoelastometer Methods

Viscoelastometer measurements are being conducted by G. A. Engel (research in progress at NPS) utilizing basically the same procedures described by Bieda (1970). However, a newly designed viscoelastometer is being used. Additionally, measurements are made

at 20°C vice 9°C. Presently, problems are being encountered in viscoelastic measurements, and data were not obtained in time to be included in this report. Work in this area will be described in a future report.

III. PRESENTATION OF DATA

A. STATION LOCATION, WATER DEPTH, AND BOTTOM WATER TEMPERATURE

The location of each station and corresponding water depth are listed in Table I. Water depths were obtained utilizing a precision depth recorder, and navigational fixes were obtained primarily by LORAN (Long Range Radio Navigation).

B. TEXTURAL ANALYSES

Mean grain size and sand/silt/clay ratios for each 6-inch core section are listed in Table II. No sand/silt/clay ratio information is given for Section 1 of Core 6 because the coarse fraction of the sample was lost because of accidental spillage. Sand/silt/clay ratios are plotted on a Shepard Tertiary Diagram in Figure 4. Depth in the core is also listed in Table II.

C. MASS PHYSICAL PROPERTIES

Wet density, water content, porosity, and maximum shear strength for each 6-inch core section are listed in Table III. Vane shear profiles are presented in Figures 5 to 32 (the point at which maximum torque was measured is marked with a circle). Maximum shear strength was calculated from the shear strength formula of Wilson (1964):

$$S = \frac{T}{\pi\left(H\frac{D^2}{2} + \frac{D^3}{6}\right)}, \qquad (3)$$

where

S	=	maximum shear strength (psi),
T	=	maximum torque (inch-lb),
H	=	vane height (0.75 inches), and
D	=	vane diameter (0.75 inches).

D. ACOUSTIC PROPERTIES

Sediment to water sound speed ratio, bottom water sound speed, and in situ sediment compressional wave speed are listed in Table IV. Values of bottom water sound speed were obtained from tables (U. S. Naval Oceanographic Office, 1966).

IV. DISCUSSION AND CONCLUSION

Available data were analyzed and possible correlations between compressional wave speed and mass physical properties were investigated. Before discussing these possible correlations, it is necessary to note apparent trends and characteristics of all mass physical data which were obtained.

The basic mass physical properties (wet density, water content, and porosity) followed obvious and predictable trends. As depth in the core increased, wet density increased, and water content and porosity decreased. These variations with respect to depth in the core are considered to be the result of increased sediment consolidation as depth below the sediment surface is increased. Regarding sand/silt/clay ratios, all core section samples with the exception of one, Section 3 of Core 3, fell into the clay or silty clay classification. The sand content of Section 3 of Core 3 was unusually high compared to other core sections possibly because the section contained a layer of sand. In some core sections, layers of sand were visually noted (these sediments are turbidites); however, occurrence of these layers was relatively infrequent and appeared to be random. Other core sections having relatively high sand contents were Section 6 of Core 1B and Section 2 of Core 2. No correlations were apparent between either mean grain size or sand/silt/clay ratio and relative geographic location, water depth, or depth in the core. Likewise, no correlations were apparent

between either wet density, water content, or porosity and mean grain size or sand/silt/clay ratio (Figures 33 to 41).

Of all the mass physical properties investigated in this report, vane shear measurements were considered the most significant. It was felt that these measurements offered the greatest potential for establishing correlations between the mass physical properties and acoustic properties. Moore (1964) relates shear strength to other parameters as follows:

$$S = \tau_f = C + (\sigma - U) \tan \phi, \qquad (4)$$

where

S = shear strength,

τ_f = shear stress on the failure plane at failure,

C = apparent cohesion,

σ = total load normal to the failure plane,

U = pore water pressure, and

ϕ = angle of internal friction.

It can be seen from this relationship that the measured shear strength equals cohesion (as Moore contends) if pore water pressure equals the total load normal to the failure plain, a condition which exists if the sediment is in an undrained state. Bryant and Delflache (1971) have reached the same conclusion regarding shear strength measurements of undrained sediment samples. Vane shear measurements described in this report were conducted on undrained samples. To prevent drainage prior to testing, shear tests were conducted on sediment-filled core sections within a few minutes after sectioning was accomplished

at sea. Additionally, the vane rotation rate, 20°/min, enabled shear testing to be accomplished before significant drainage could occur. The justification for this choice of vane rotation rate is based on the opinions of other investigators. Bryant and Delflache (1971) performed vane shear tests on deep water sediments from the Gulf of Mexico utilizing a motorized vane shear apparatus with a rotation rate of 20°/min. Inderbitzen and Simpson (1969) reported that their vane shear test results from an apparatus with a vane rotation rate of 6°/min could have been affected by drainage which occurred while the test was being conducted. Taylor and Demars (1970) also stated that laboratory vane shear rates which were too slow could result in higher shear strengths due to drainage.

Analysis of the vane shear profiles yielded a completely unexpected characteristic for all cores but one. The value of maximum shear strength (cohesion) did not reach its highest value at the bottom of the core. Instead, the highest value of maximum shear strength was found at an intermediate depth in all cores with the exception of Core 8. Simpson and Inderbitzen (1970) also detected this unexpected characteristic in some cores obtained along a gullied section of the upper San Diego Trough slope off Del Mar, California. In situ vane shear testing by NCEL (Taylor and Demars, 1970) resulted in maximum shear strength occurring at the greatest depth in the sediment and not at an intermediate depth. It is felt that the occurrence of the highest value of maximum shear at an intermediate depth in the core is quite possibly the result of disturbance of the sediment during the coring process. In addition

to graphically displaying maximum shear strength, the vane shear profiles illustrate the behavior of the sediment before and after failure occurs. The initial slope of the profile before failure occurs should be proportional to the elastic modulus because the profile is basically a graph of stress vs. strain. The average initial slope was found to be approximately 4.8 inch-lb per 10° of rotation. The initial slopes of most core sections were within a small margin of this average value. However, a minimum value of 2.0 inch-lb per 10° of vane rotation and a maximum value of 6.9 inch-lb per 10° of vane rotation were encountered. Initial slopes of the profiles did not appear to be proportional to depth in the core. Generally, failure occurred within 20° to 35° of vane rotation. After failure, some profiles illustrate a partial recovery of shear strength after a minimum value of shear strength had been reached. This tendency was virtually nonexistent in core sections taken from within 1 ft of the top of the core. Some profiles have radical dips which are the result of either drive motor belt slippage or ship motion which momentarily reduced torque on the vane. It can also be noted that some profiles do not begin at the origin of the axes; this is the result of mechanical "play" in the linkage between the upper and lower components of the Wykeham-Farrance Vane Shear Machine. Proper alignment prior to testing can eliminate this problem.

Correlations between values of maximum shear strength and any of the other mass physical properties could not be made. Figures 33, 34, 35, and 36 are plots of vane shear strength vs. mean grain ,

wet density, water content, and porosity respectively. Analysis of these graphs revealed no relationships between the parameters plotted.

Correlations between compressional wave speed in the sediment and mass physical properties were investigated. In situ sediment compressional wave speed is plotted against vane shear strength, mean grain size, wet density, water content, and porosity in Figures 37, 38, 39, 40, and 41 respectively. Analysis of these graphs produced no correlations with one exception. Figure 37, a plot of vane shear strength vs. in situ compressional wave speed, shows a general increase in sound velocity as shear strength increases. Only comparisons between two parameters, one acoustical property and one mass physical property, were attempted. Other investigators in this area of research, including Cernock (1970), have generally not been successful in establishing useful relationships between acoustical and mass physical properties. Cernock (1970), however, has achieved some success in establishing correlations between bulk density, porosity, and median grain diameter for sediments which demonstrate a relationship between cohesion and sound speed. It is felt that more research in this area is required.

Perhaps the most significant benefit gained from the research described in this report was the increase in understanding of the laboratory vane shear test. However, familiarization with the vane shear method made apparent a number of shortcomings. First, as the vane was inserted into the sediment, it was noted that the sediment was disturbed. How this disturbance affected the vane shear measu[illegible]nt

is not known. Secondly, as the vane was rotated, disturbance of the sediment was observed at varying distances from the cylinder of sediment failure. This disturbance took the form of radial cracks originating from the cylinder. Vane shear theory takes into account the dimension of the cylinder but does not take into account disturbances away from the cylinder. Thirdly, no standardization of test parameters has been established for vane shear testing. Parameters such as vane rotation rate, blade size, number of blades, and sediment container size have not been specified for the testing of marine sediments. Lastly, because the laboratory vane shear test is not an in situ test, possible undesirable and unpredictable factors caused by sampling procedures may distort data. Vey and Nelson (1968) have indicated that environmental pressure may affect soil properties. In addition to the unknown effects caused by removal of environmental pressure, it is felt that mechanical disturbance of the sediment during coring operations results in data distortion.

V. SUMMARY

Research described in this report provided valuable experience and familiarization with the vane shear device. It is felt that the vane shear provides useful data which can partially describe the physical nature of marine sediments. However, the vane shear measurement of shear strength must be made under conditions which assure validity of data. Samples must be tested before drainage can occur and adversely affect vane shear measurements by producing erroneously high readings. In addition to drainage of core samples, other adverse factors must be considered and minimized if at all possible. These factors are disturbance of the sediment when the vane is lowered into the sample, disturbance of the sediment at varying distances from the vane as the vane is rotated, and disturbance of the sediment during coring operations. Although the factors just described undoubtedly result in unpredictable and undesirable effects upon vane shear measurements, it is felt that these factors do not completely invalidate vane shear data.

All mass physical measurements, including vane shear measurements, performed in conjunction with research described in this report were made utilizing simple and inexpensive equipment. The vane shear equipment was also readily transportable and compatible with a shipboard environment. Performing vane shear measurements on the research vessel instead of in the laboratory greatly reduced the possibility of sediment drainage. The mass physical measurements which were made provide a fairl

extensive data base to describe the physical characteristics of the sediment samples obtained. Although correlations between the mass physical properties were not apparent, it is expected that the data base is sufficient to investigate correlations between mass physical properties and viscoelastic parameters when viscoelastic data is made available.

On a quantitative basis, as depth in the core increased, wet density increased, and porosity and water content decreased. These trends were anticipated. An exception to anticipated trends was the observation that the maximum value of shear strength was found mid-point in the core. Whether this resulted from disturbance during coring or some other cause is not known.

VI. RECOMMENDATIONS

Vane shear testing is one of five independent methods for measuring shear strength. The vane shear should continue to be utilized, but not without standardization of test parameters. Singler (1971) has made recommendations for selection of vane shear test parameters. Although there may be disagreement regarding his selections, more emphasis must be placed on selection and standardization of testing guidelines. It is recommended that this selection be arbitrary to prevent delays which would result from research necessary to investigate the complex relationships between test parameters. Furthermore, it is recommended that vane shear testing be done in situ to prevent disturbance of the sediment from coring operations. The Naval Civil Engineering Laboratory has performed in place shear tests from its deep submergence platform, DOTIPOS (Demars and Taylor, 1971). Although it has been recommended to continue and improve vane shear testing, research emphasis must also be placed on the development of dynamic methods of determining shear strength. Carpenter, Thompson, and Bryant (unpublished paper) have proposed a means of calculating shear strength by measuring the deceleration of a projectile fired into the sediment by a modified recoilless rifle which can be lowered to within firing distance of the ocean bottom.

TABLE I

STATION LOCATION, WATER DEPTH, AND BOTTOM WATER TEMPERATURE

Coring Station	Latitude N	Longitude W	Water Depth fm(m)	Bottom Water Temperature, °C
1B	36-45	123-16	1830(3347)	1.592
2	36-48	123-06	1745(3191)	1.803
3	36-48.5	123-20	1802(3295)	1.552
4	36-48	123-25	1900(3475)	1.548
5	36-44	123-28	1955(3575)	-
6A	36-40.5	123-17	1883(3444)	1.610
7	36-43.5	123-10	1917(3505)	1.630
8	36-44	123-01	1690(3091)	1.559

TABLE II

TEXTURAL ANALYSIS

Core	Section	Depth in the Core inches	Mean Grain Size ∅	Sand %	Silt %	Clay %
1B	2	14	9.71	1.35	19.64	79.01
	4	34	9.66	1.09	20.92	77.99
	6	54	7.71	18.38	34.92	46.70
2	2	16	7.91	17.91	28.64	53.45
	4	36	9.72	.78	21.51	77.71
	6	53	9.71	.40	20.19	79.41
3	1	3	9.11	8.51	22.03	69.82
	3	24	7.73	31.40	19.36	49.24
	5	44	9.06	3.73	27.79	68.48
4	1	3	9.75	1.01	19.43	79.56
	3	23	9.78	.43	19.50	80.07
	5	44	9.12	6.22	24.97	68.81
5	1	3	9.53	1.35	22.79	75.86
	3	23	9.86	.48	17.19	82.33
	6	57	8.99	2.19	31.85	65.96
6A	1	3	9.73			
	2	8	9.80	.39	18.92	80.69
	4	28	9.46	.47	24.86	74.67
	6	48	8.64	3.25	37.76	58.99
	8	69	8.52	3.25	43.33	53.42
7	1	3	9.55	.93	24.03	75.04
	3	23	9.80	.36	19.54	80.10
	5	43	8.90	2.70	26.78	70.52
	7	63	8.82	1.61	36.82	61.57
	8	69	8.19	8.95	40.93	50.12
8	1	3	9.70	1.14	18.75	80.11
	3	23	9.59	.53	21.1[illegible]	78.36
	5	43	9.48	.50	24.11	75.39

TABLE III

MASS PHYSICAL PROPERTIES

Core	Section	Wet Density g/cm^3	Water Content %	Shear Strength psi	Porosity %
1B	2	1.29	141	0.659	76.8
	4	1.34	126	0.839	75.1
	6	1.46	83	0.792	66.6
2	2	1.27	169	0.198	80.9
	4	1.26	168	0.676	78.6
	6	1.31	149	0.481	80.0
3	1	1.32	137	0.396	77.3
	3	1.33	128	1.024	75.2
	5	1.37	116	0.566	74.3
4	1	1.21	210	0.532	83.3
	3	1.31	141	0.668	77.6
	5	1.39	103	0.501	71.3
5	1	1.21	207	0.260	82.5
	3	1.31	142	0.591	77.7
	6	1.38	121	0.467	76.3
6A	1	1.21	207	0.504	82.7
	2	1.23	163	0.683	77.0
	4	1.34	125	0.611	75.3
	6	1.37	114	0.450	74.0
	8	1.38	101	0.417	70.3
7	1	1.21	208	0.342	82.7
	3	1.29	145	0.577	77.6
	5	1.36	112	0.716	72.5
	7	1.41	101	0.399	72.0
	8	1.44	97	0.356	71.7
8	1	1.33	211	0.127	84.6
	3	1.28	167	0.495	80.6
	5	1.30	141	0.586	76.9

TABLE IV

ACOUSTIC PROPERTIES

Core	Section	*C sed/ C Water	Computed Bottom Water Sound Speed m/sec	Computed In Situ Sediment Sound Speed m/sec
1B	1	0.987	1512.8	1492.9
	3	0.987		1492.5
	5	0.987		1492.5
2	1	0.985	1510.9	1487.7
	3	0.982		1484.1
	5	0.981		1482.6
3	2	0.990	1511.7	1496.9
	4	0.987		1491.4
4	2	0.983	1514.9	1489.8
	4	0.981		1486.8
5	2	0.982	1516.4	1489.5
	4	0.980		1485.8
	5	0.979		1484.0
	7	0.982		1488.3
6A	3	0.981	1514.8	1485.3
	5	0.982		1487.5
	7	0.983		1488.6
7	2	0.985	1513.9	1491.5
	4	0.971		1479.3
	6	0.982		1485.9
8	1	0.980	1508.1	1478.5
	2	0.980		1478.5
	3	0.977		1473.9
	4	0.978		1474.7
	5	0.979		1477.0
	6	0.979		1477.7

*Laboratory sediment-to-water sound speed ratio

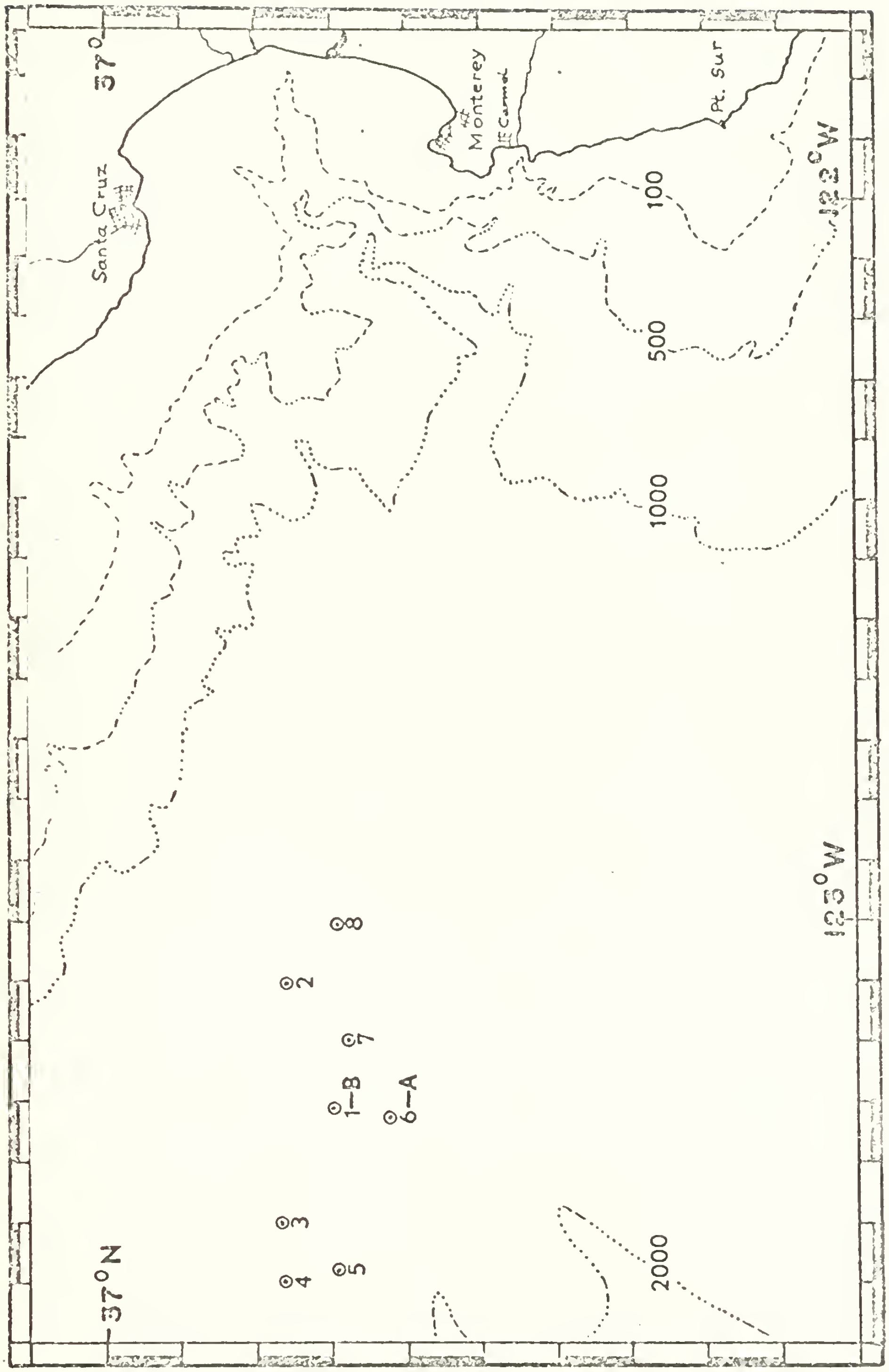

Figure 1. Coring Station Locations (Isobaths in Fathoms)

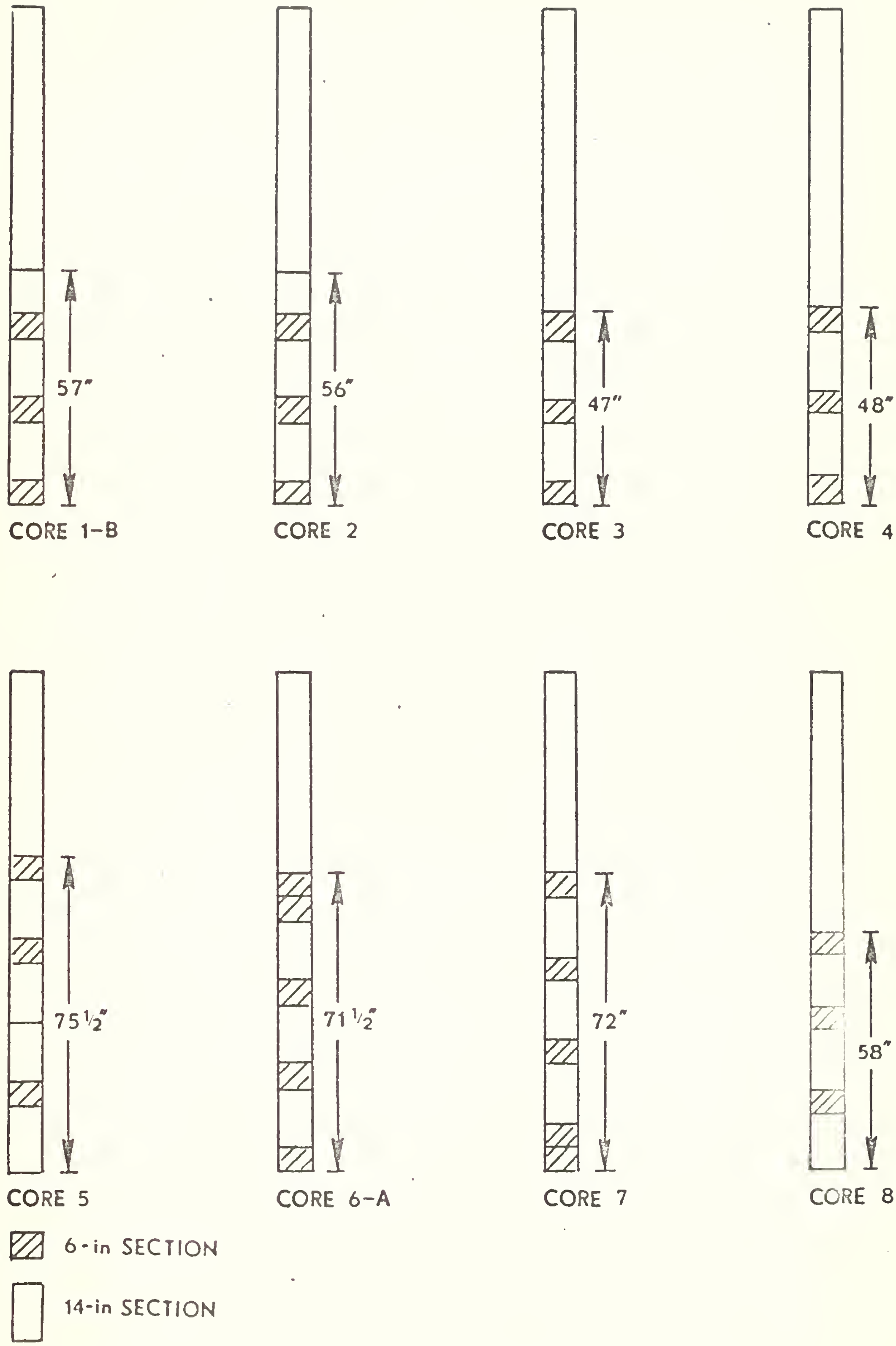

Figure 2. Sectioning of Cores

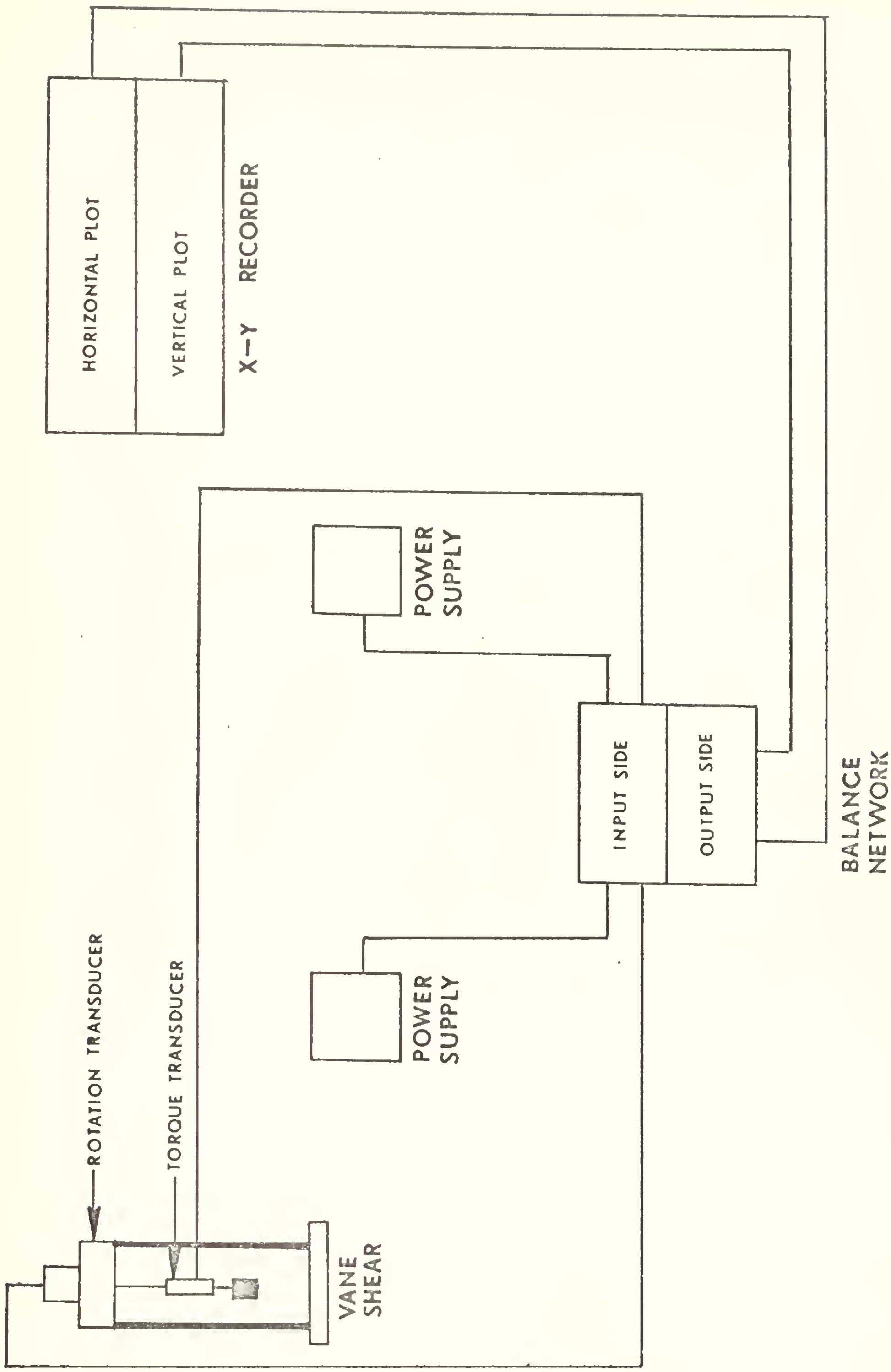

Figure 3. Block Diagram of the Wykeham-Farrance Vane Shear Machine and Associated Equipment

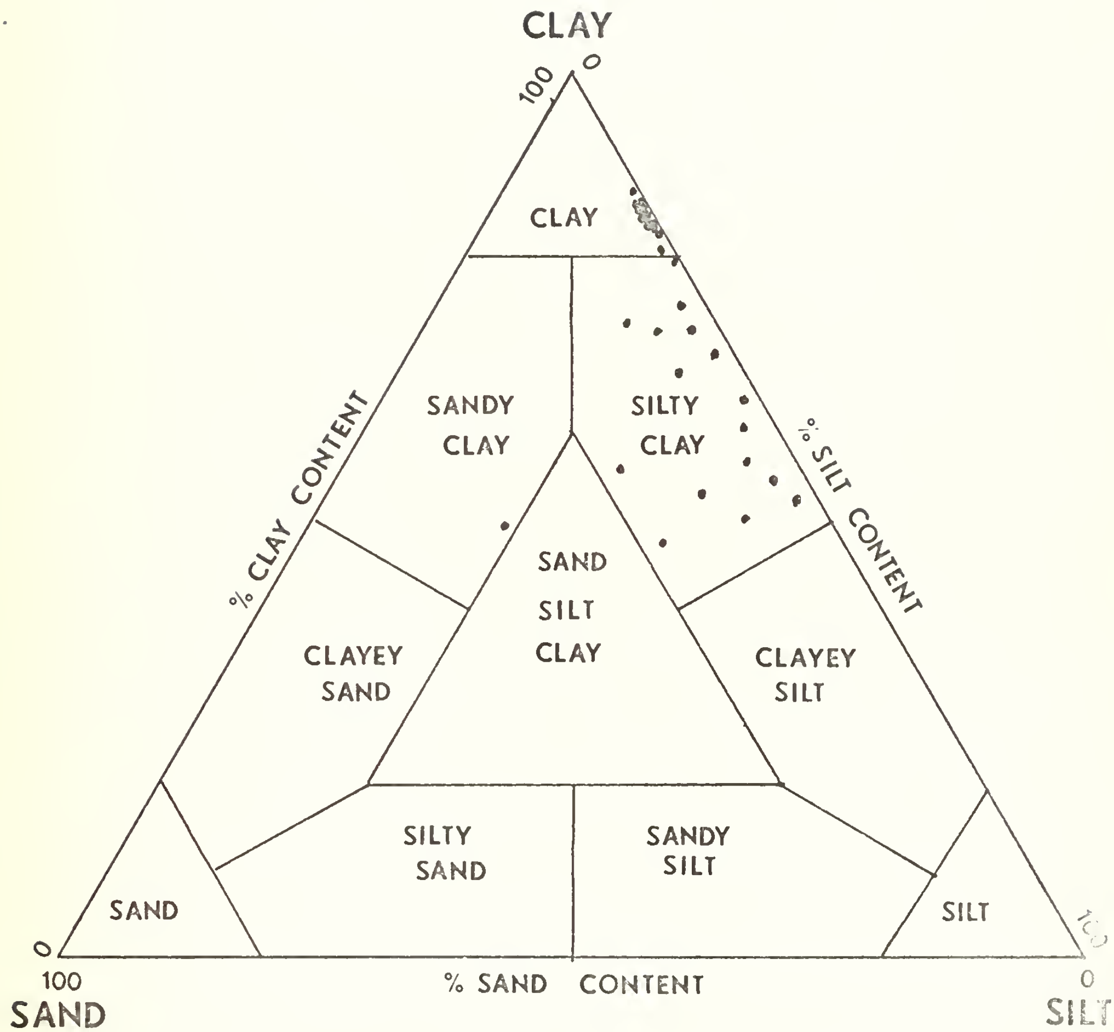

Figure 4. Plot of Sand/Silt/Clay Ratios for Each Core Section Analyzed

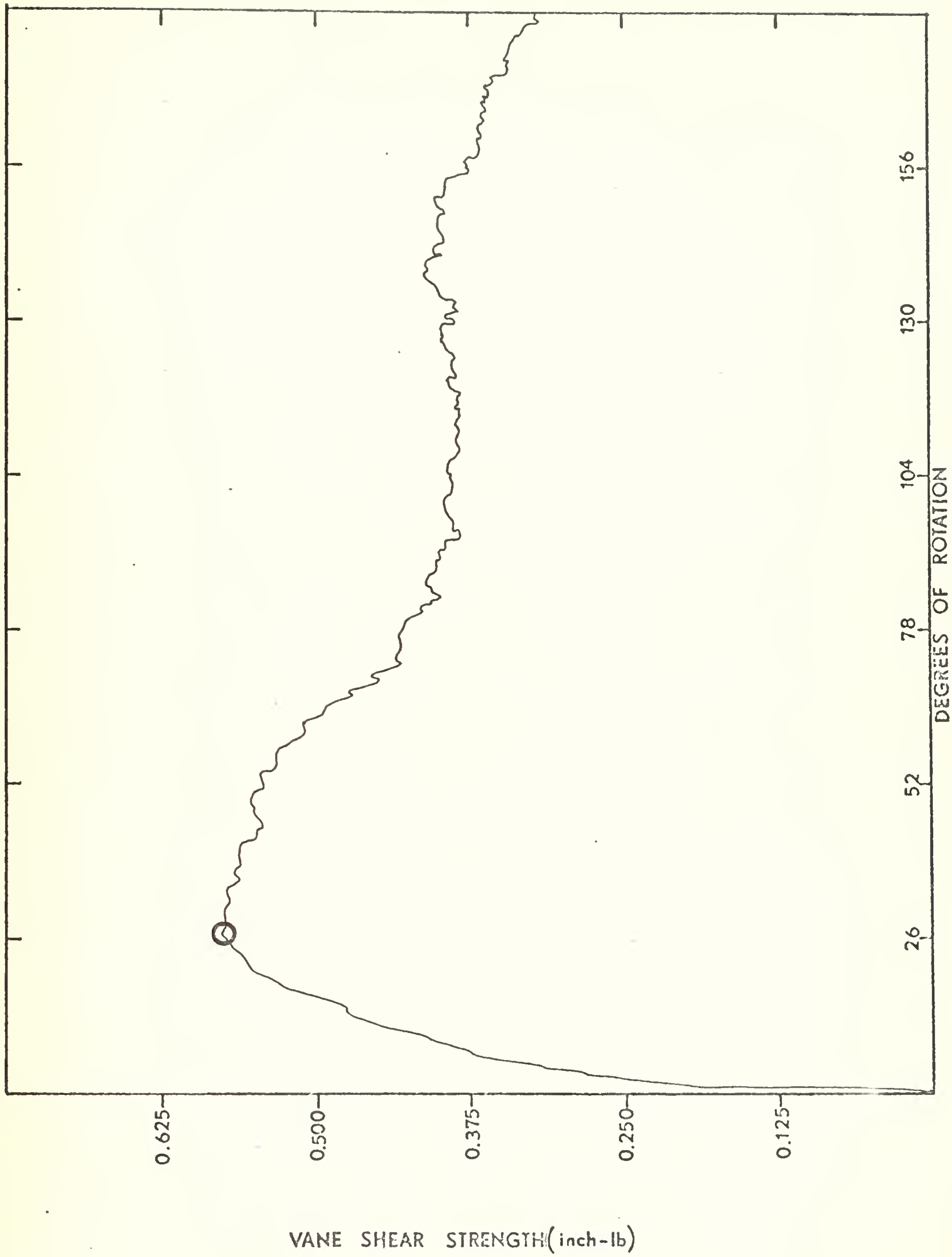

Figure 5. Vane Shear Profile of Section 2 Core 1B

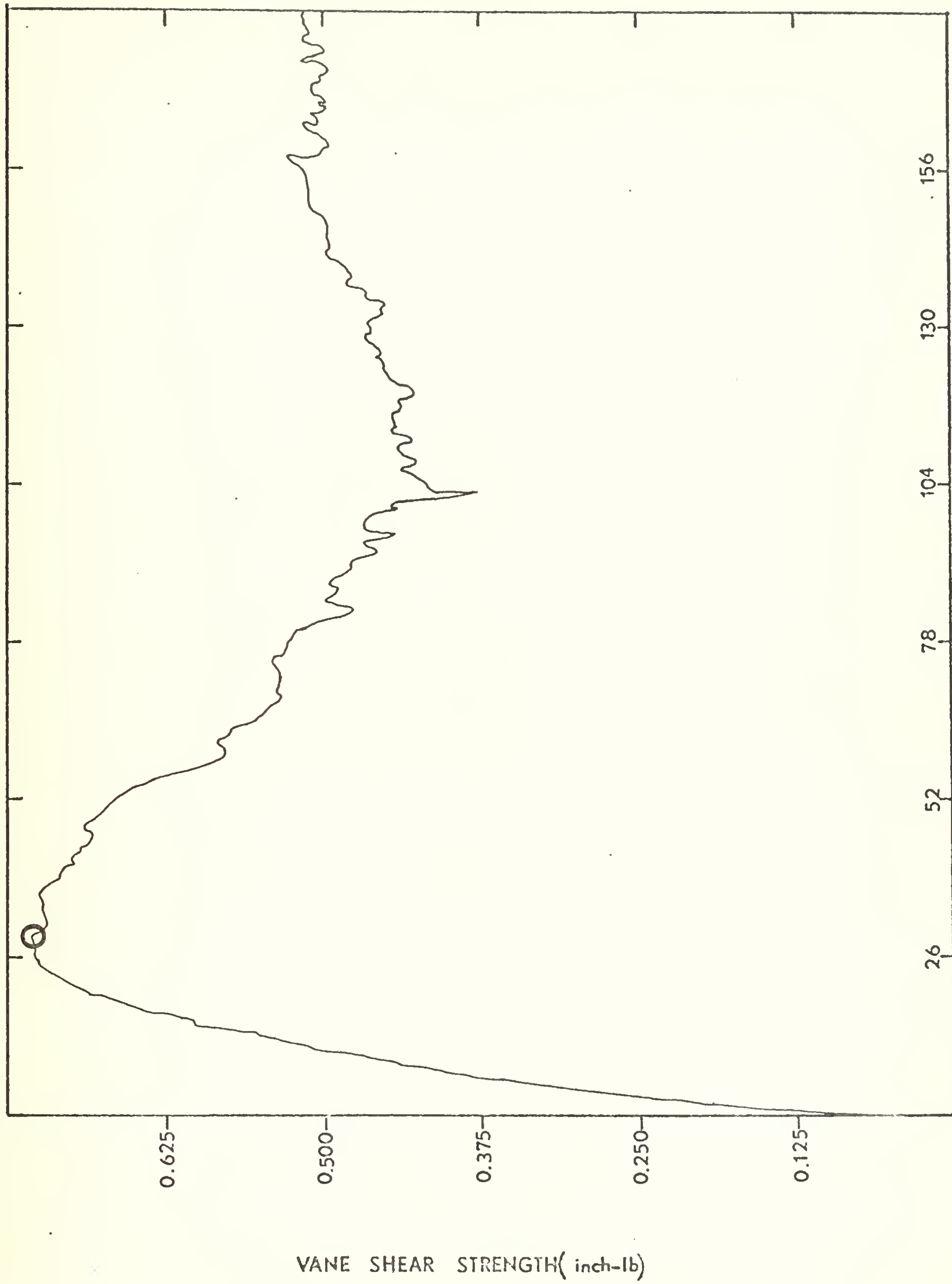

Figure 6. Vane Shear Profile of Section 4 Core 1B

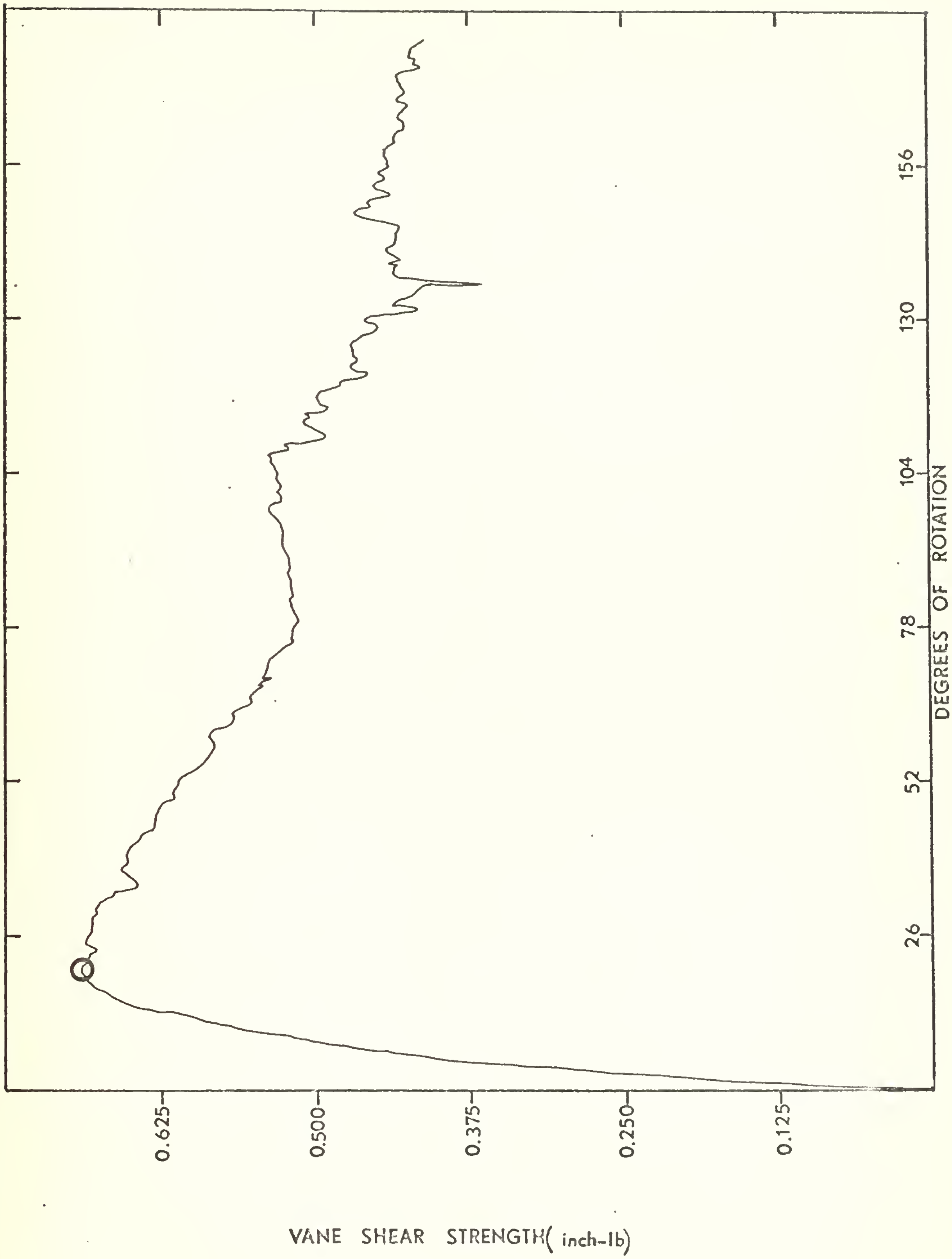

Figure 7. Vane Shear Profile of Section 6 Core 1B

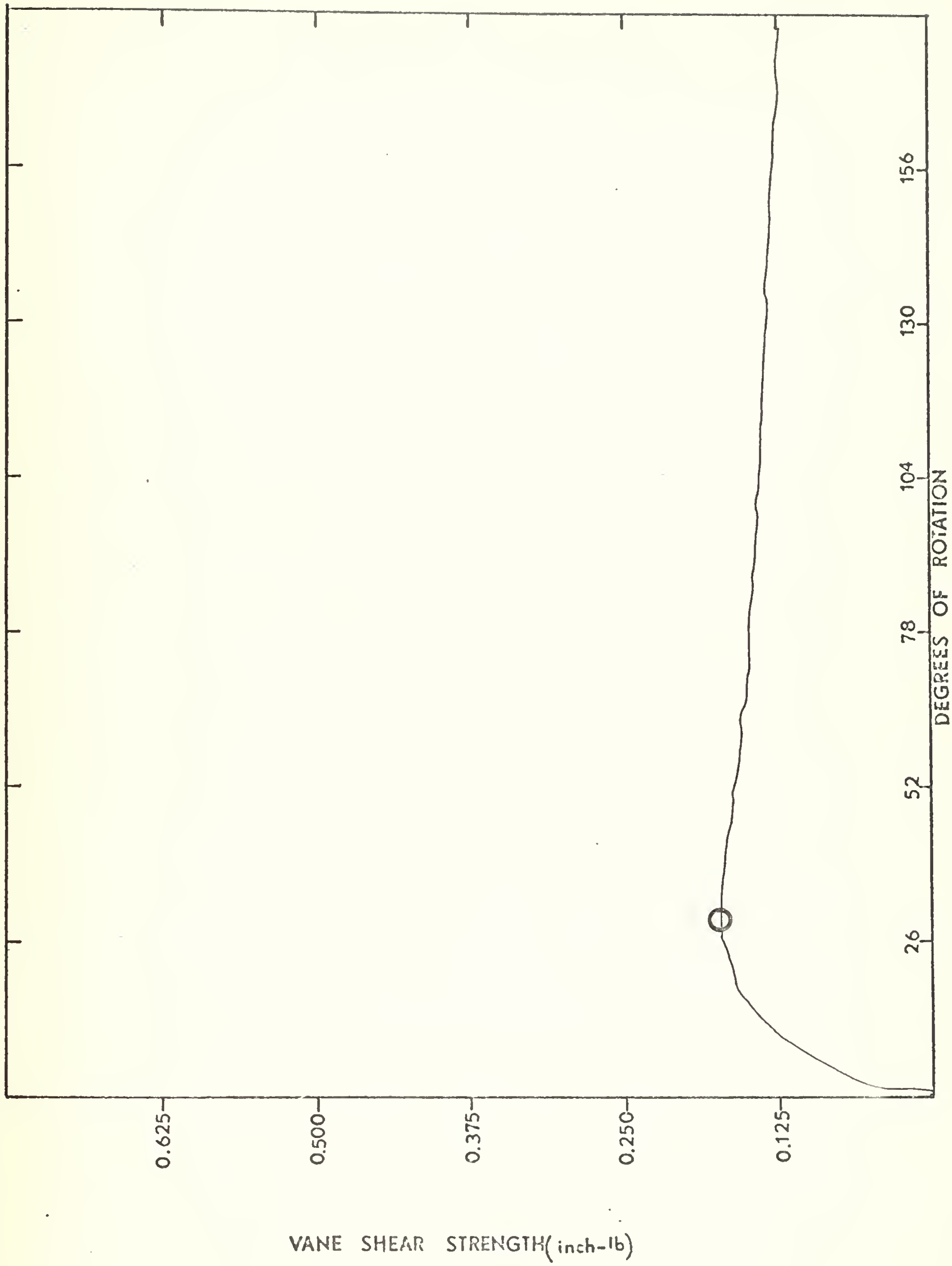

Figure 8. Vane Shear Profile of Section 2 Core 2

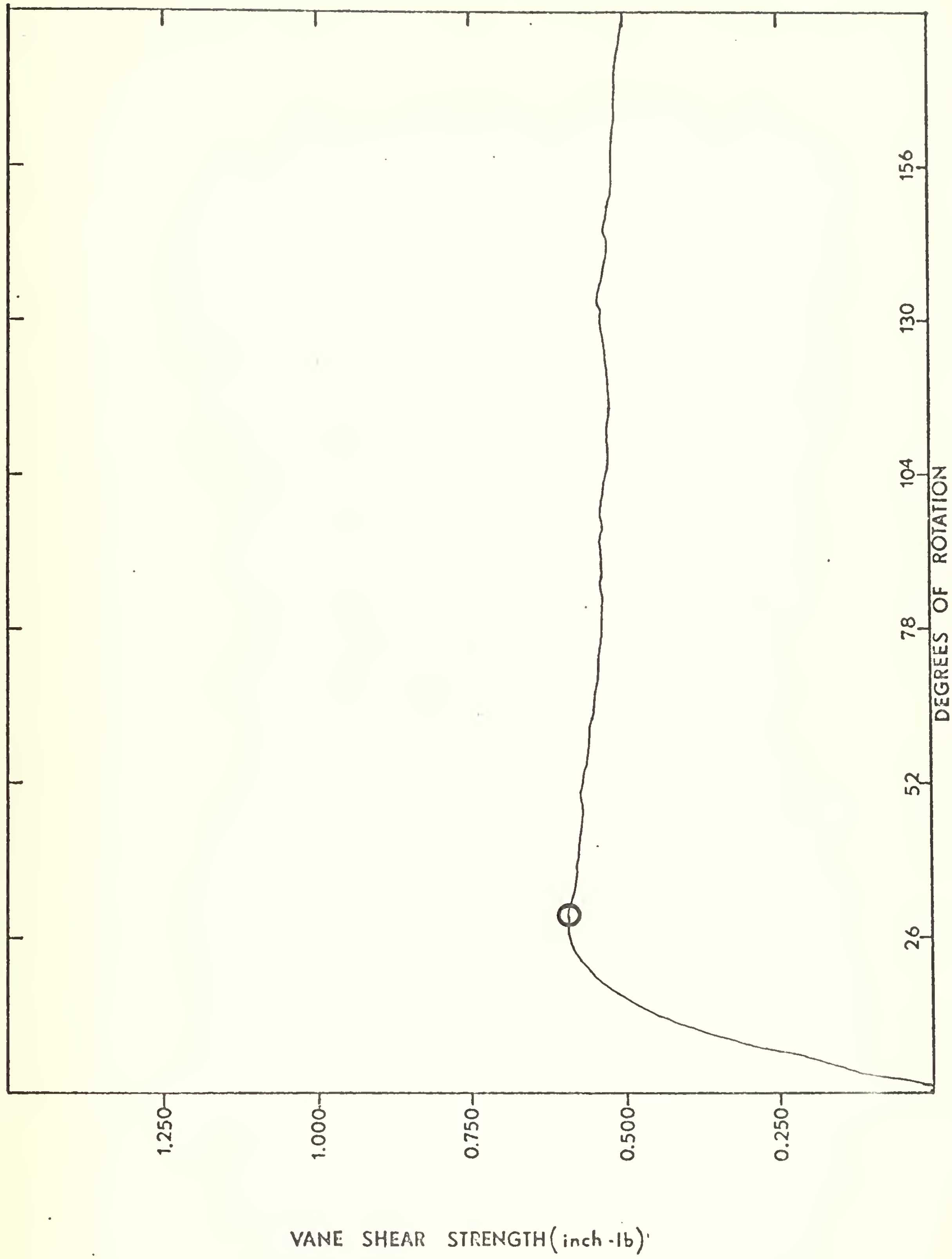

Figure 9. Vane Shear Profile of Section 4 Core 2

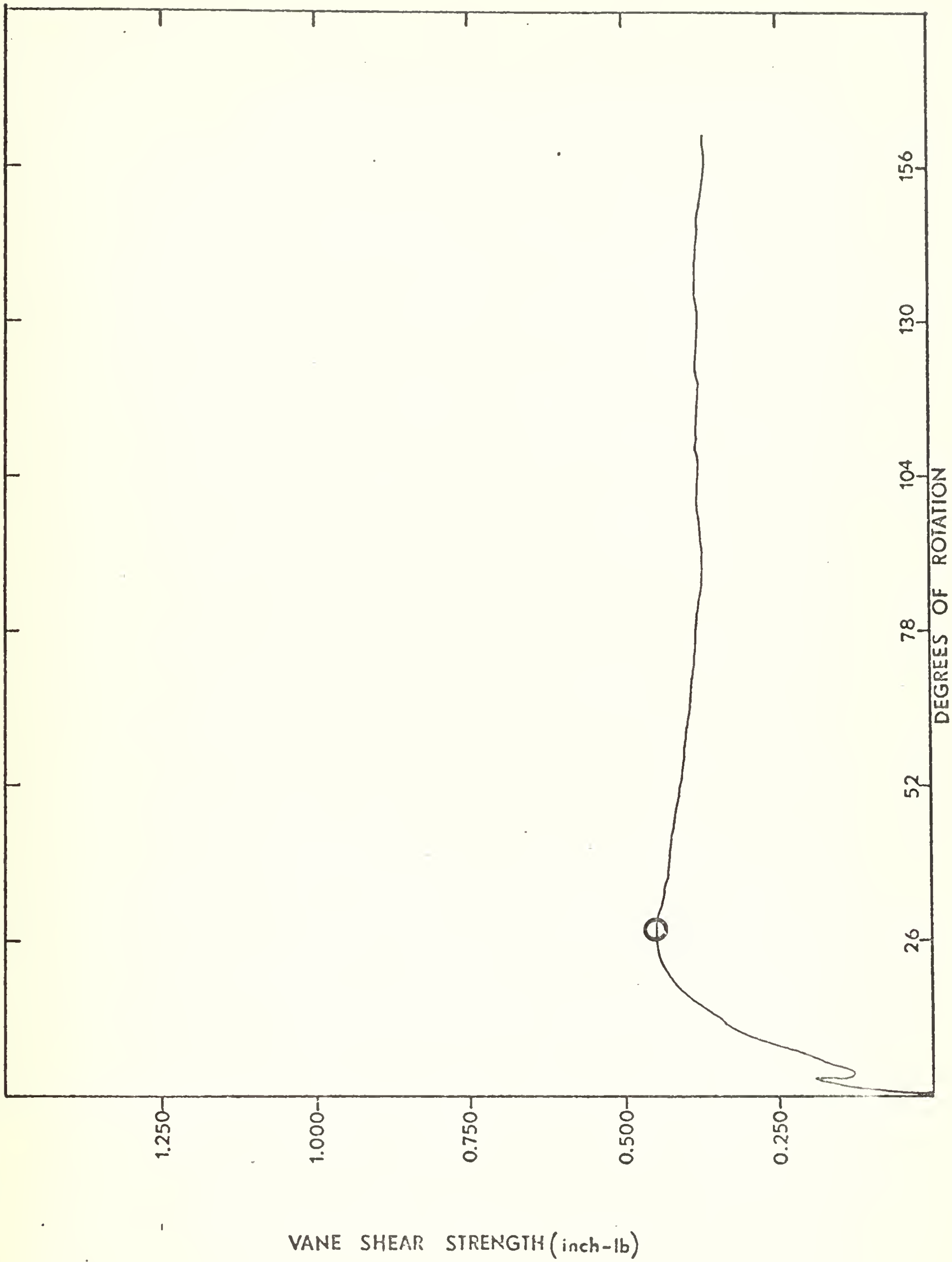

Figure 10. Vane Shear Profile of Section 6 Core 2

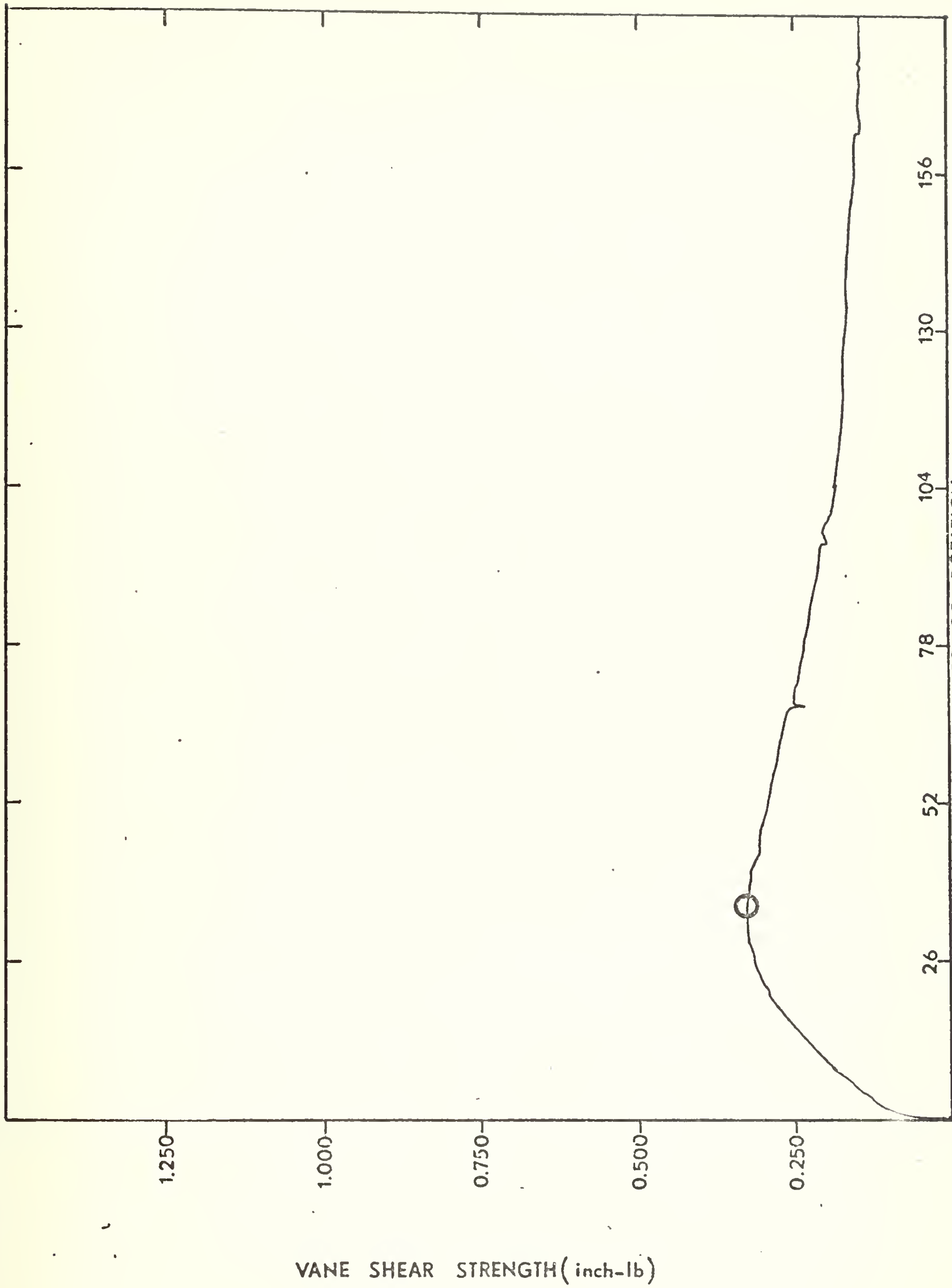

Figure 11. Vane Shear Profile of Section 1 Core 3

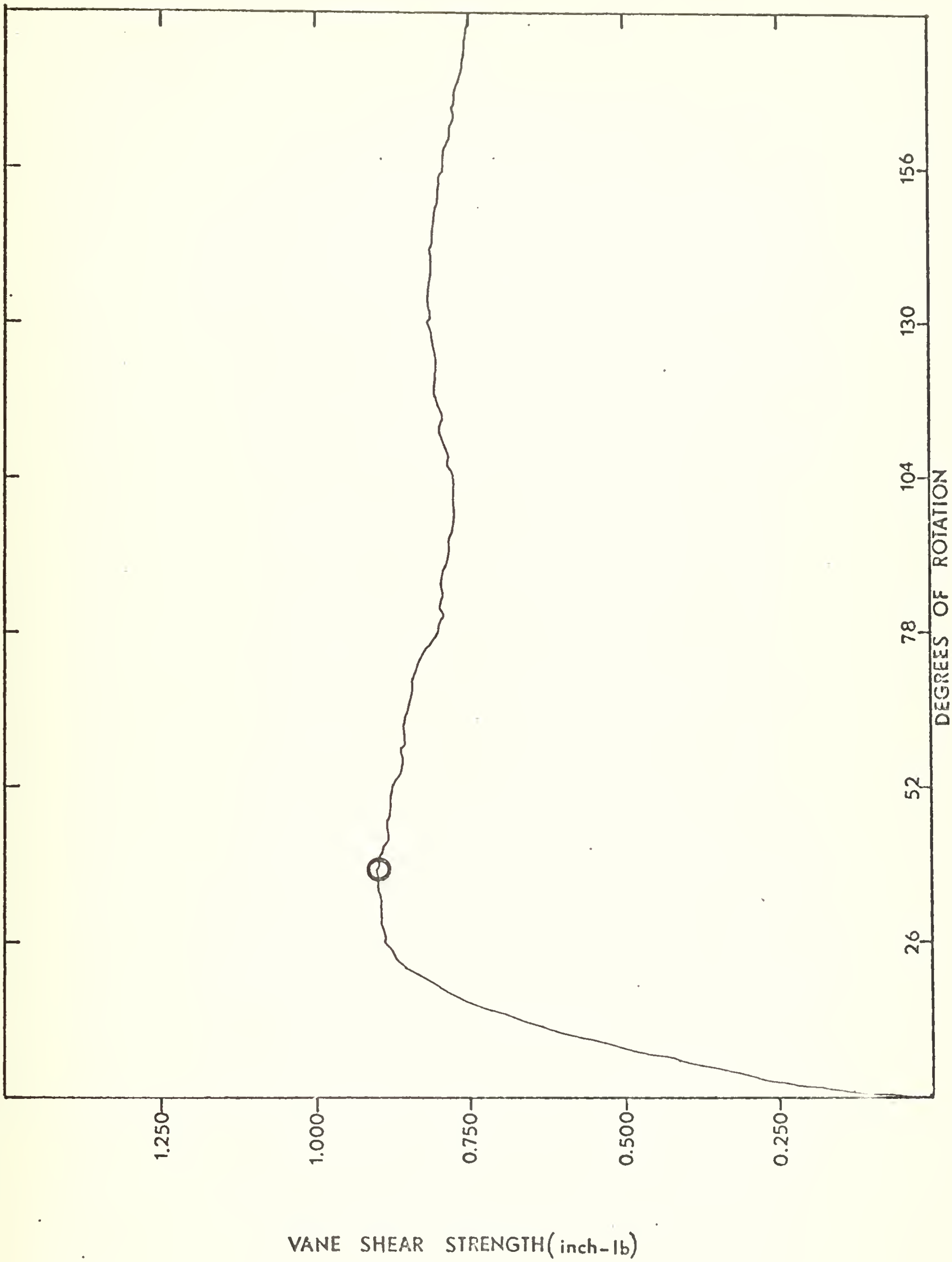

Figure 12. Vane Shear Profile of Section 3 Core 3

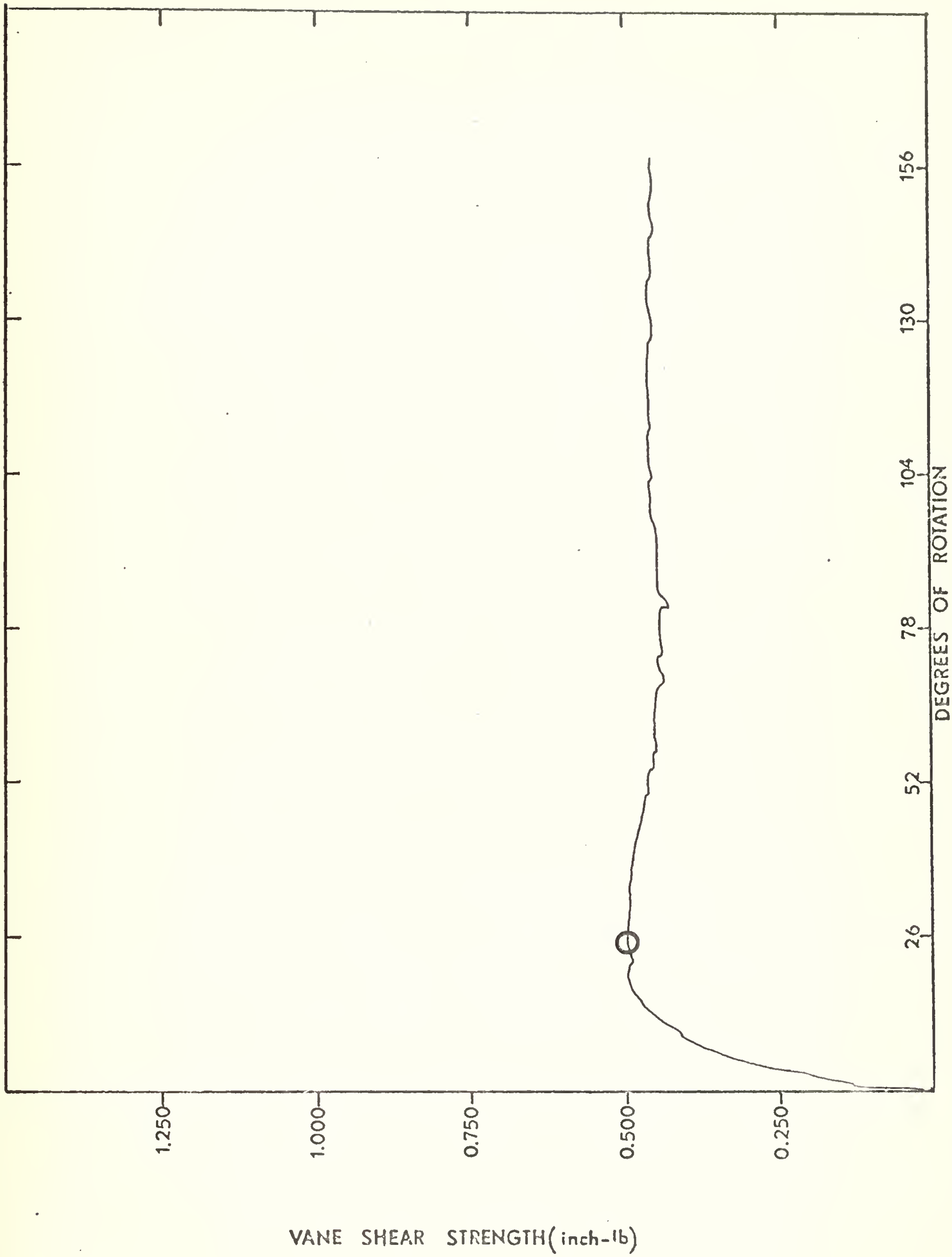

Figure 13. Vane Shear Profile of Section 5 Core 3

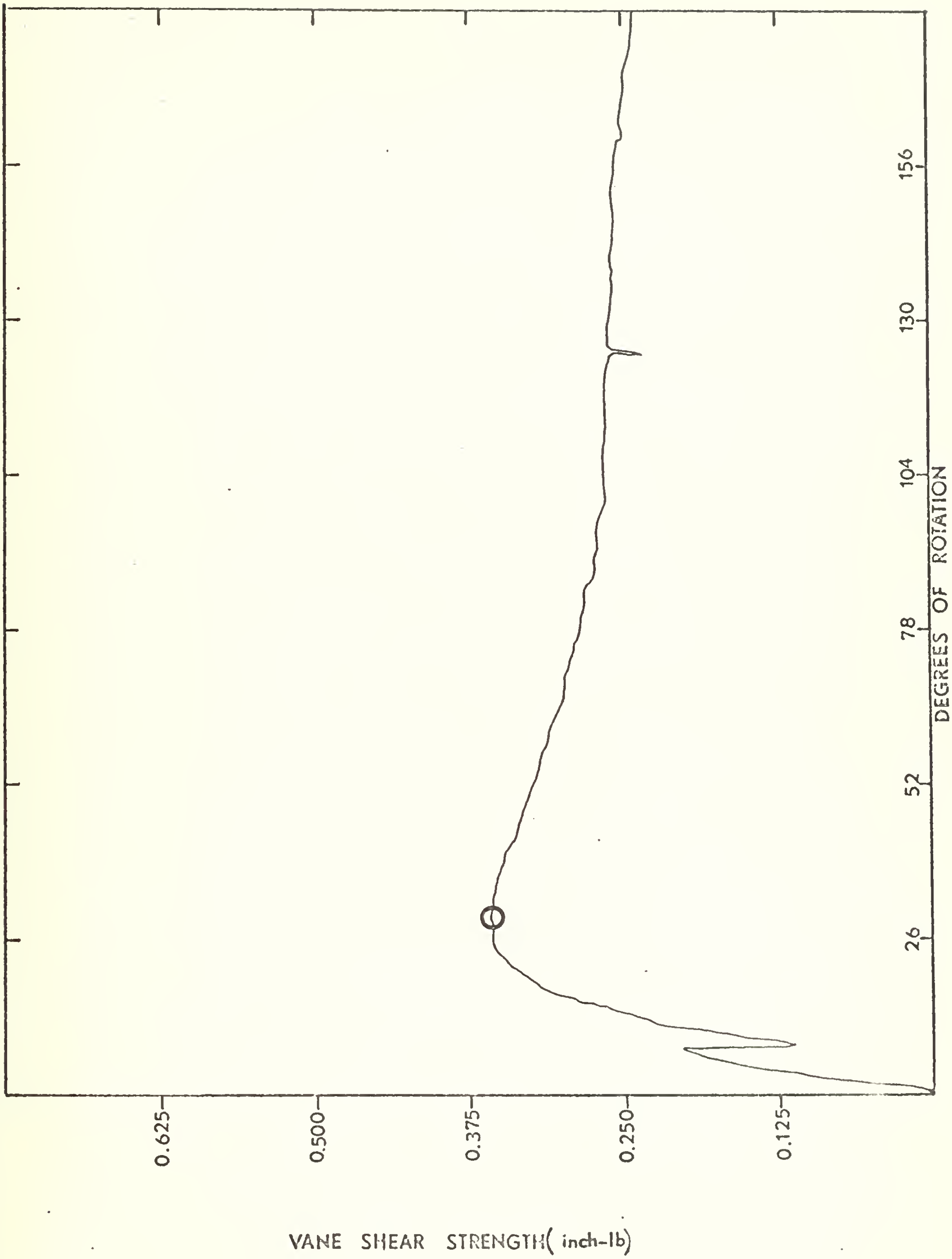

Figure 14. Vane Shear Profile of Section 1 Core 4

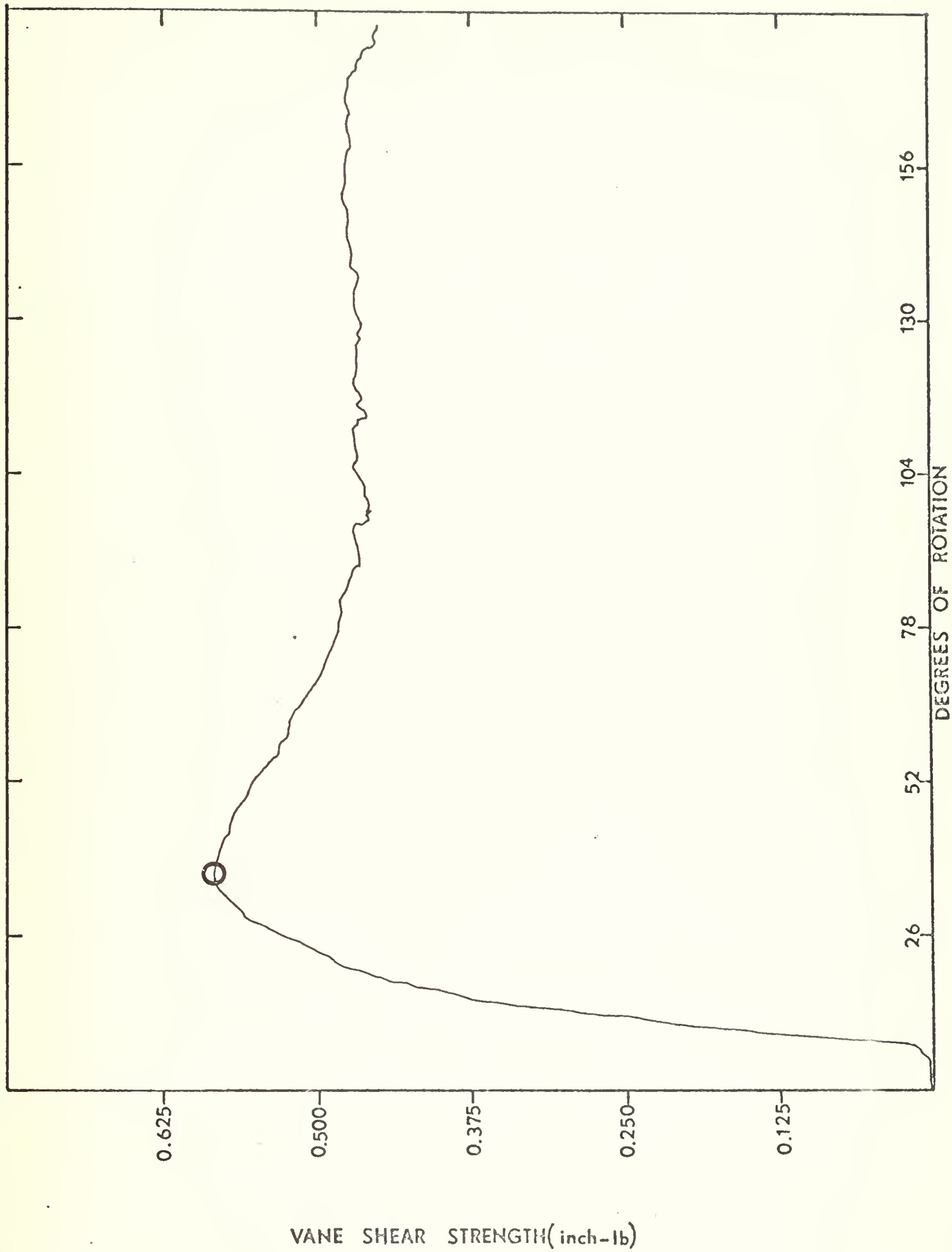

Figure 15. Vane Shear Profile of Section 3 Core 4

Figure 16. Vane Shear Profile of Section 5 Core 4

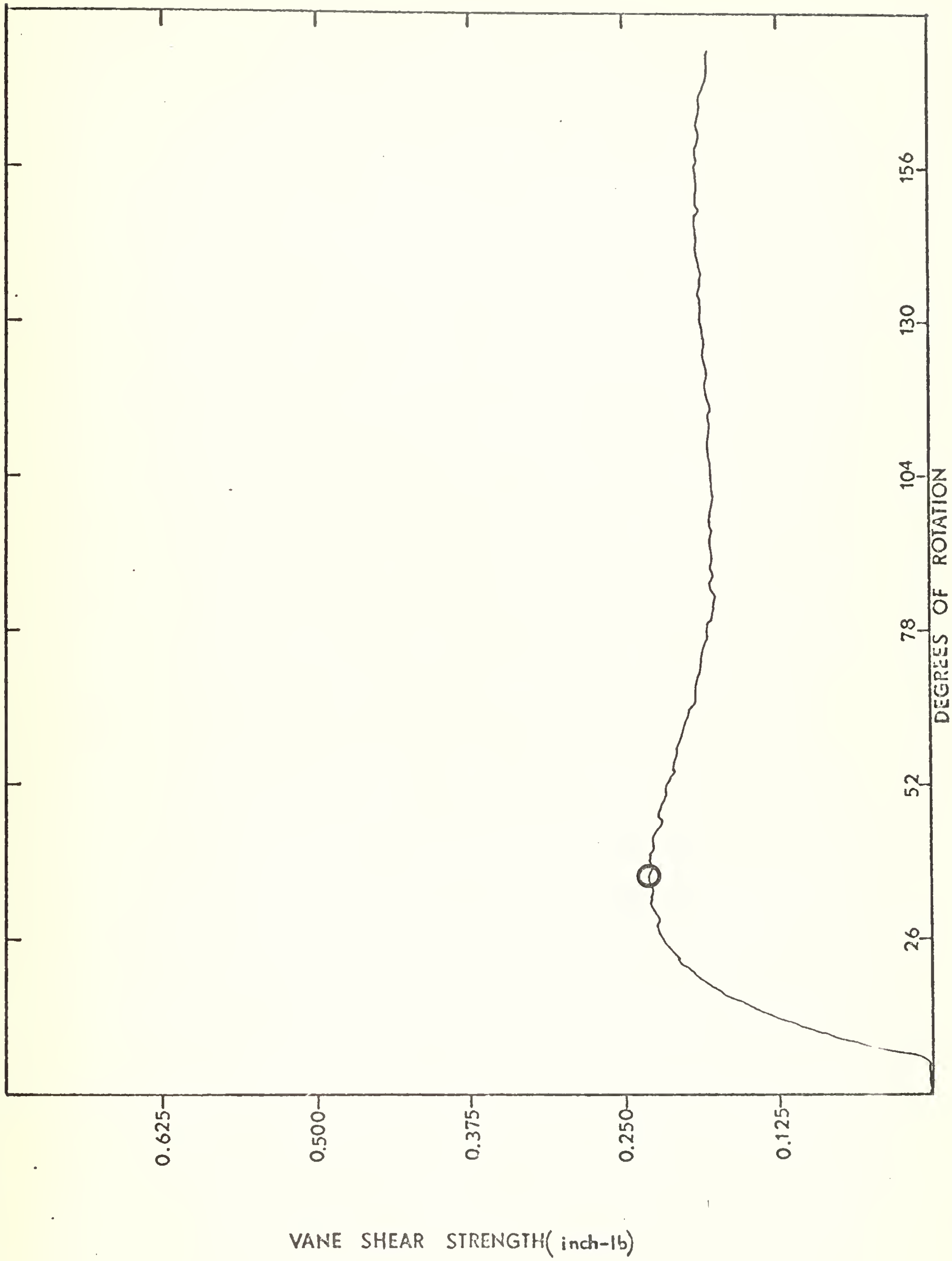

Figure 17. Vane Shear Profile of Section 1 Core 5

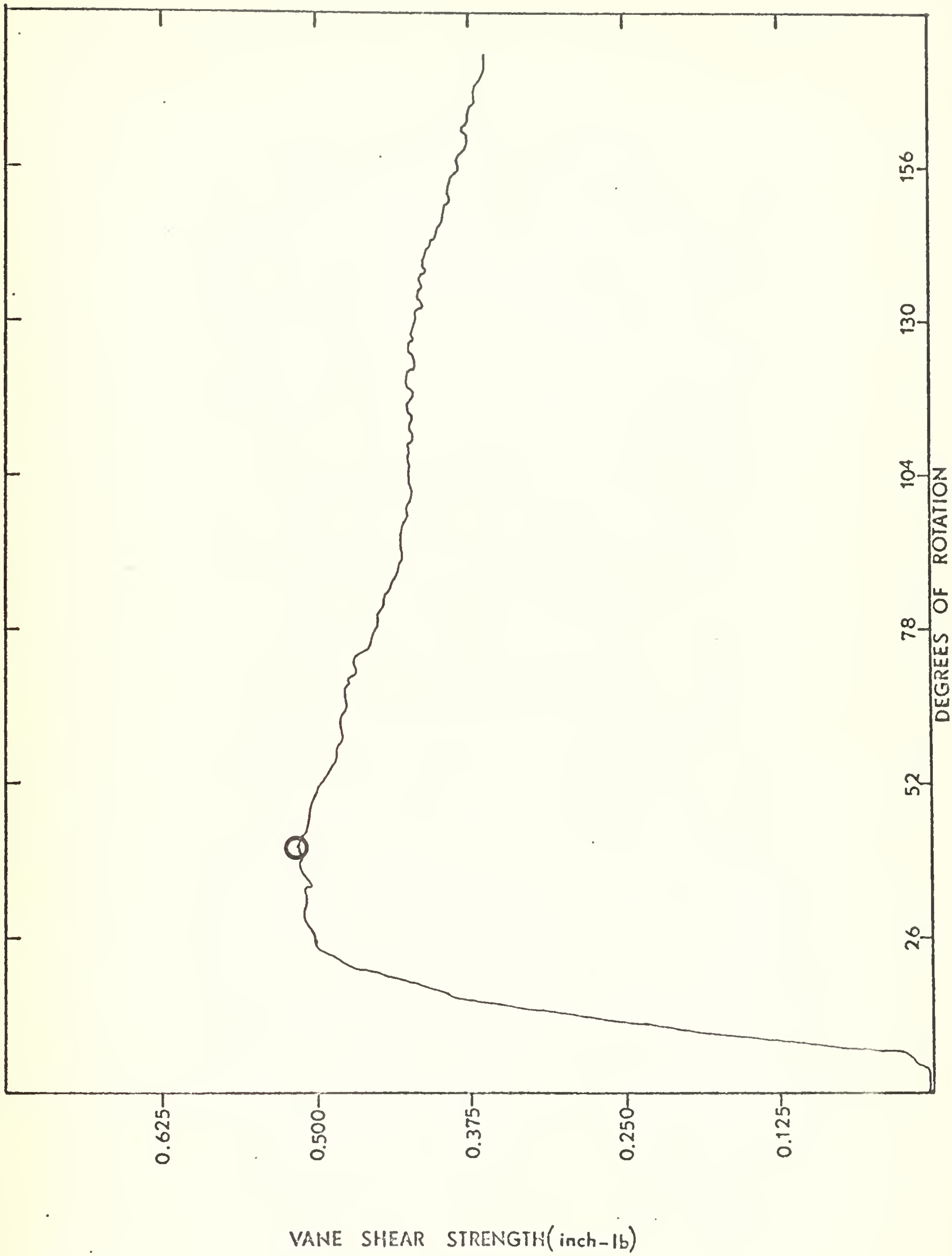

Figure 18. Vane Shear Profile of Section 3 Core 5

Figure 19. Vane Shear Profile of Section 5 Core 5

Figure 20. Vane Shear Profile of Section 1 Core 6A

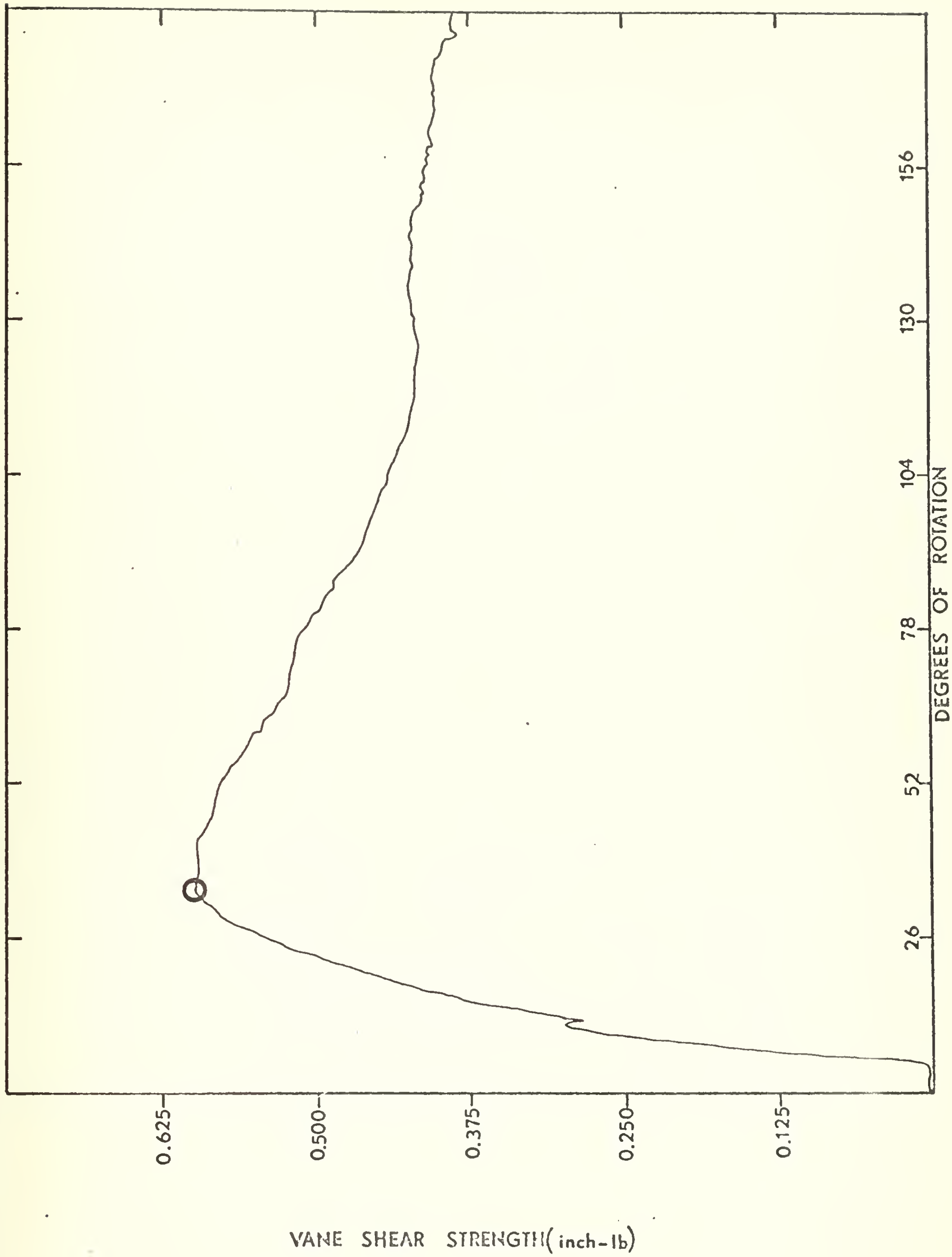

Figure 21. Vane Shear Profile of Section 2 Core 6A

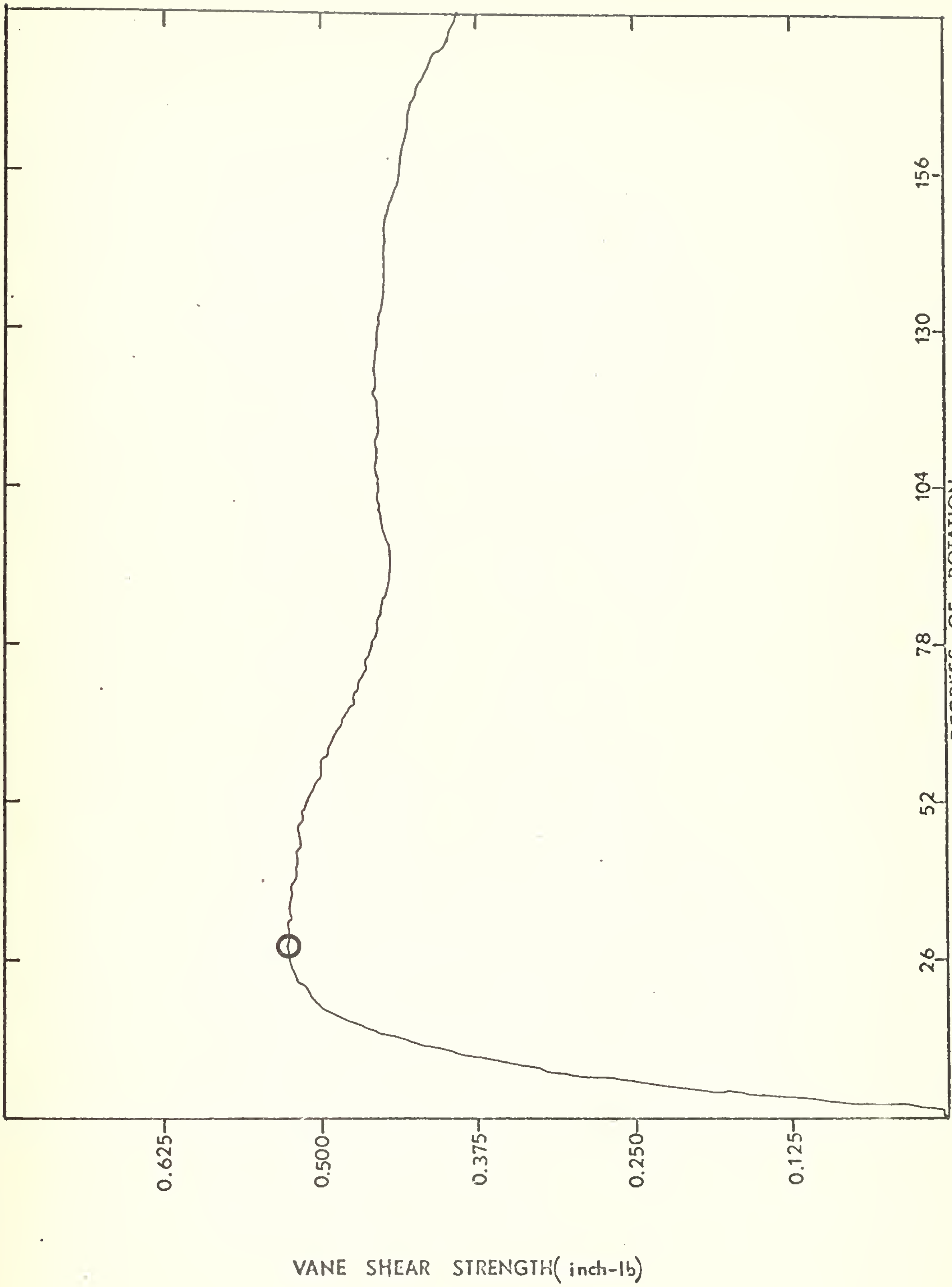

Figure 22. Vane Shear Profile of Section 4 Core 6A

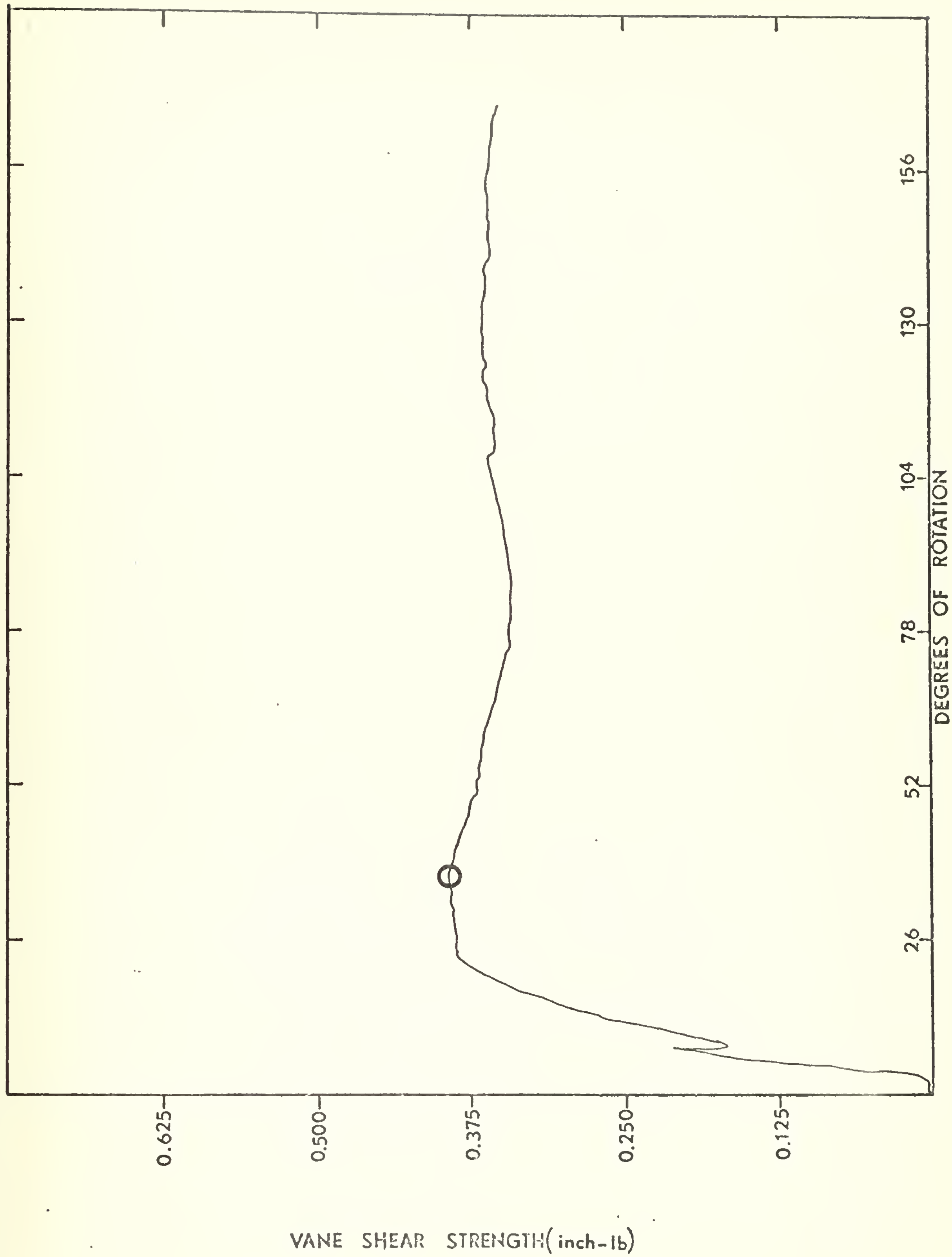

Figure 23. Vane Shear Profile of Section 6 Core 6A

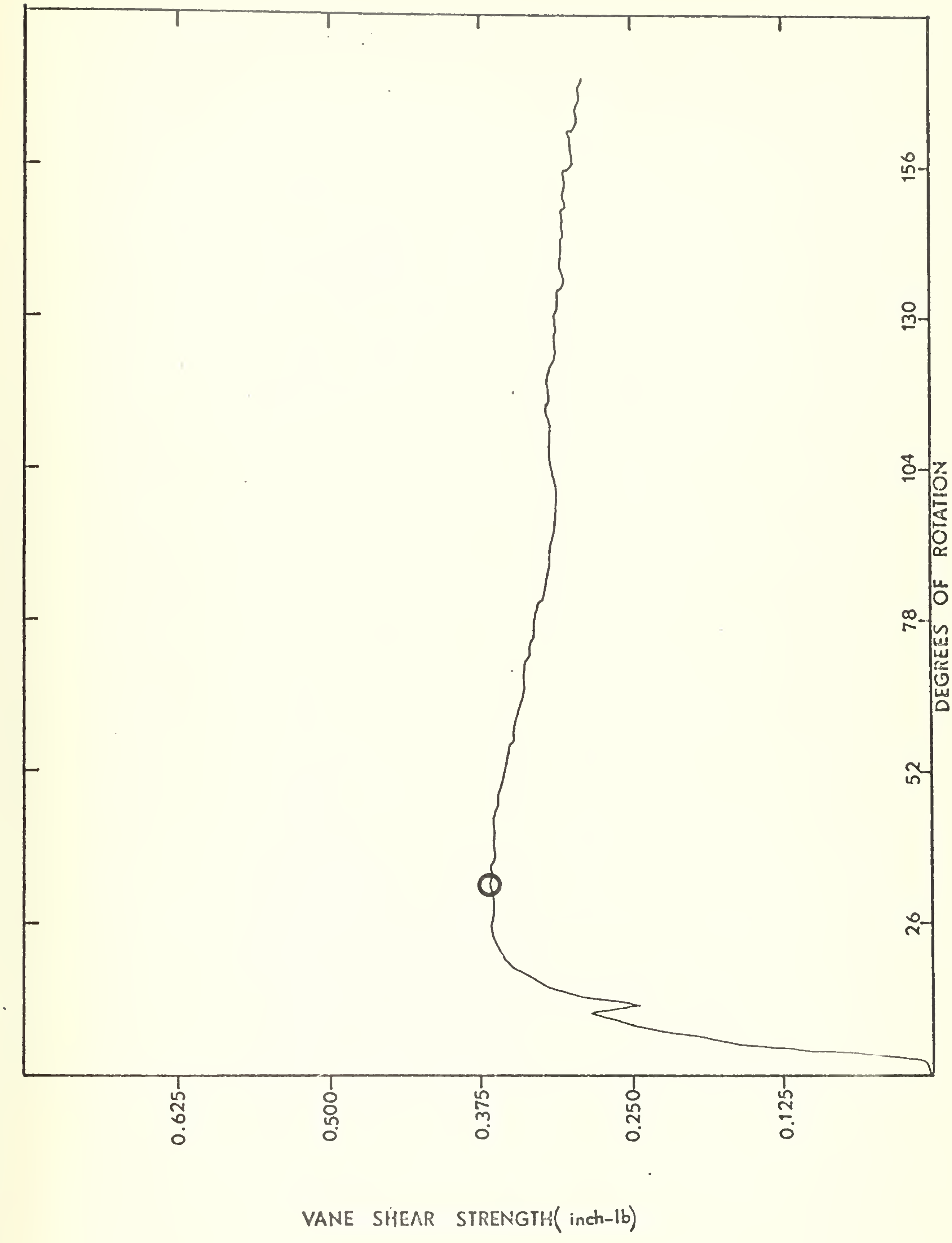

Figure 24. Vane Shear Profile of Section 8 Core 6A

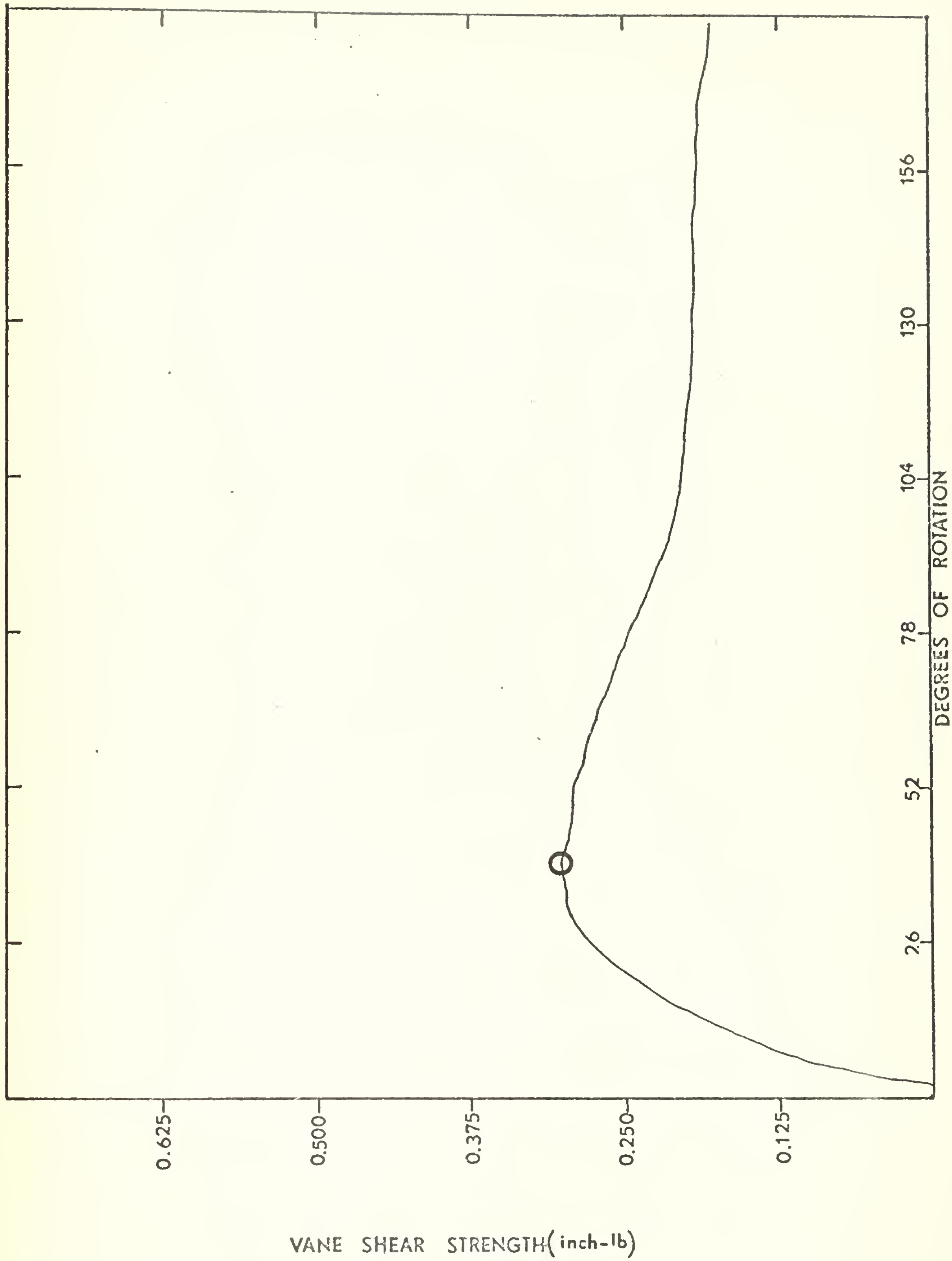

Figure 25. Vane Shear Profile of Section 1 Core 7

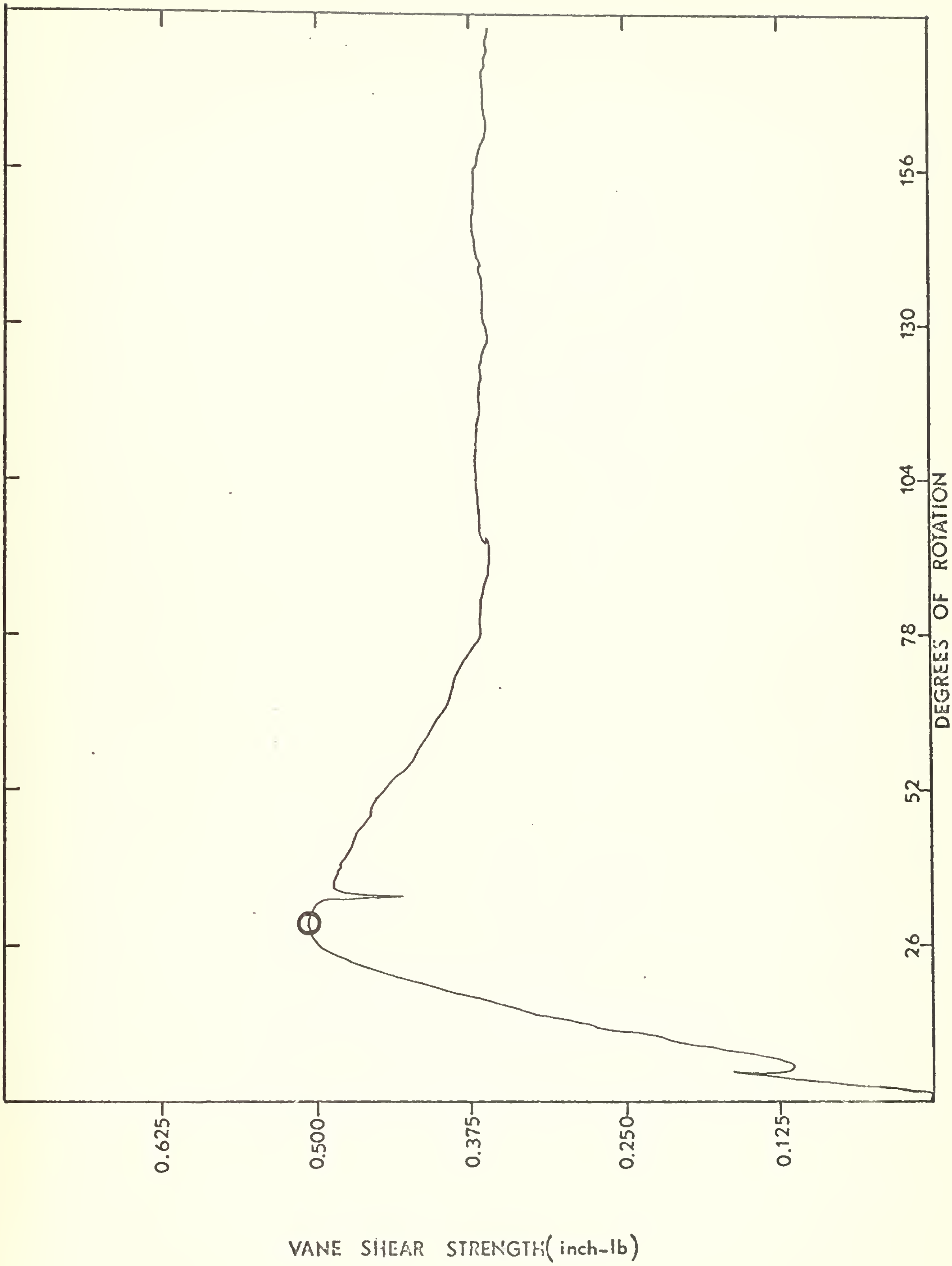

Figure 26. Vane Shear Profile of Section 3 Core 7

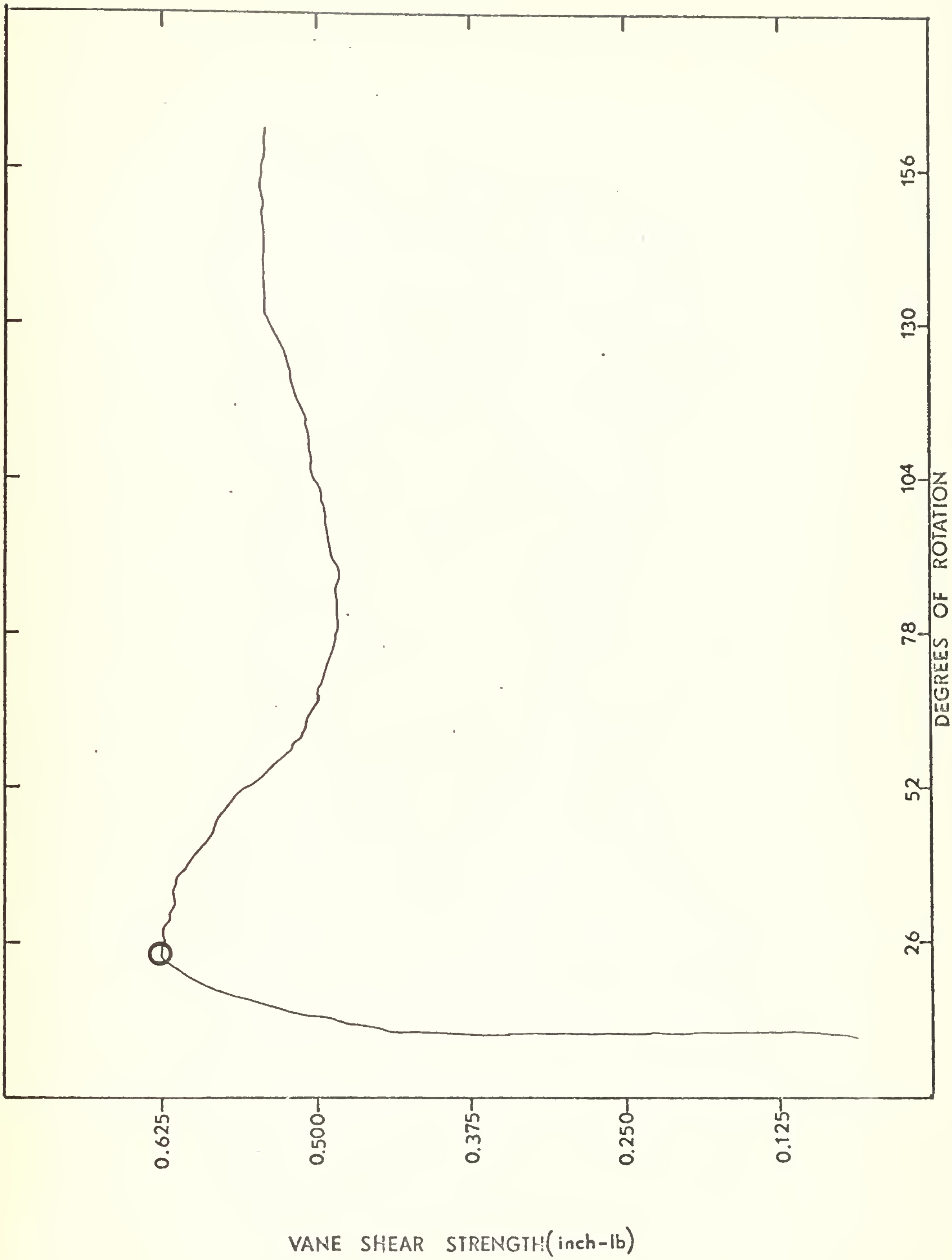

Figure 27. Vane Shear Profile of Section 5 Core 7

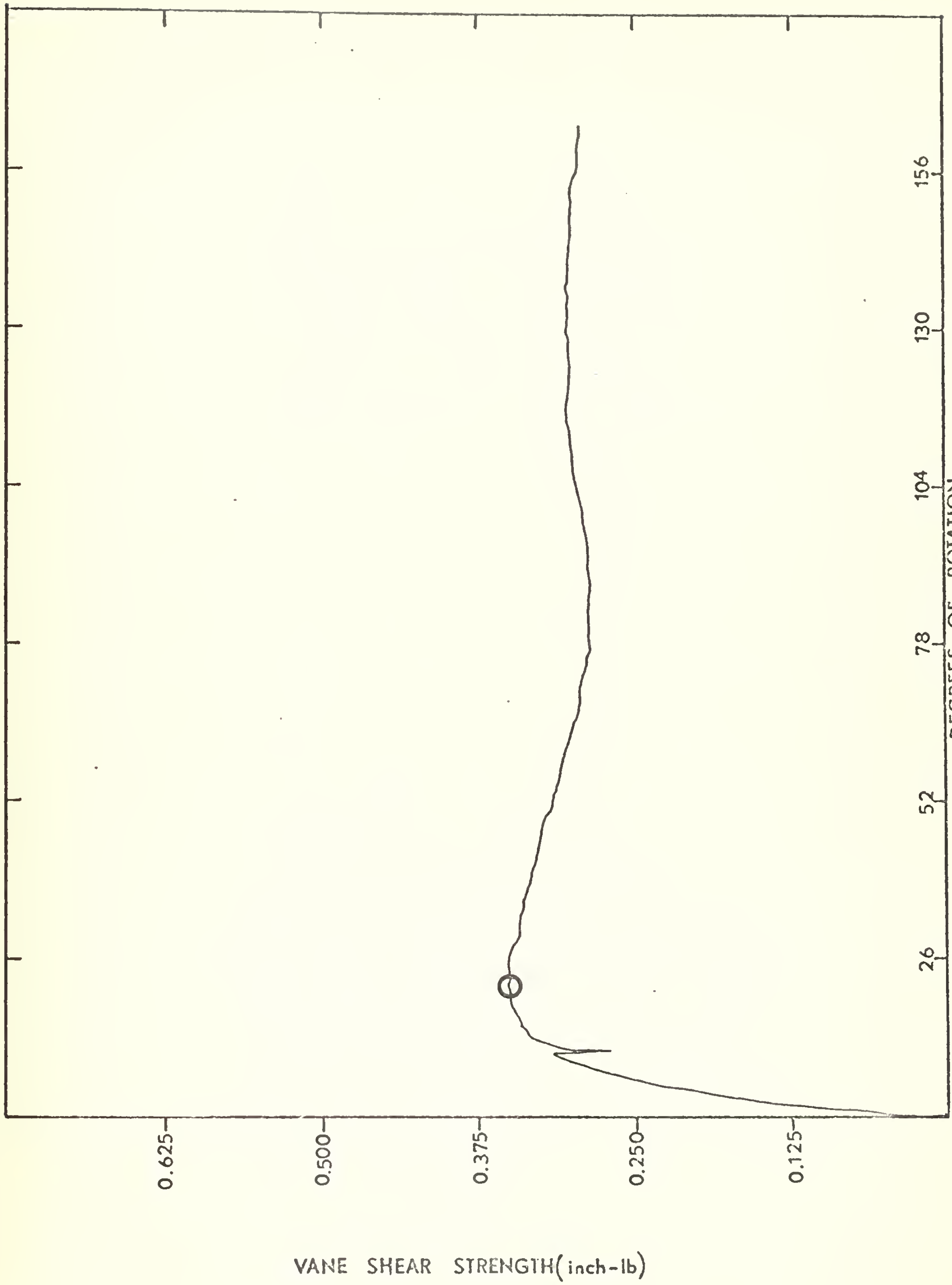

Figure 28. Vane Shear Profile of Section 7 Core 7

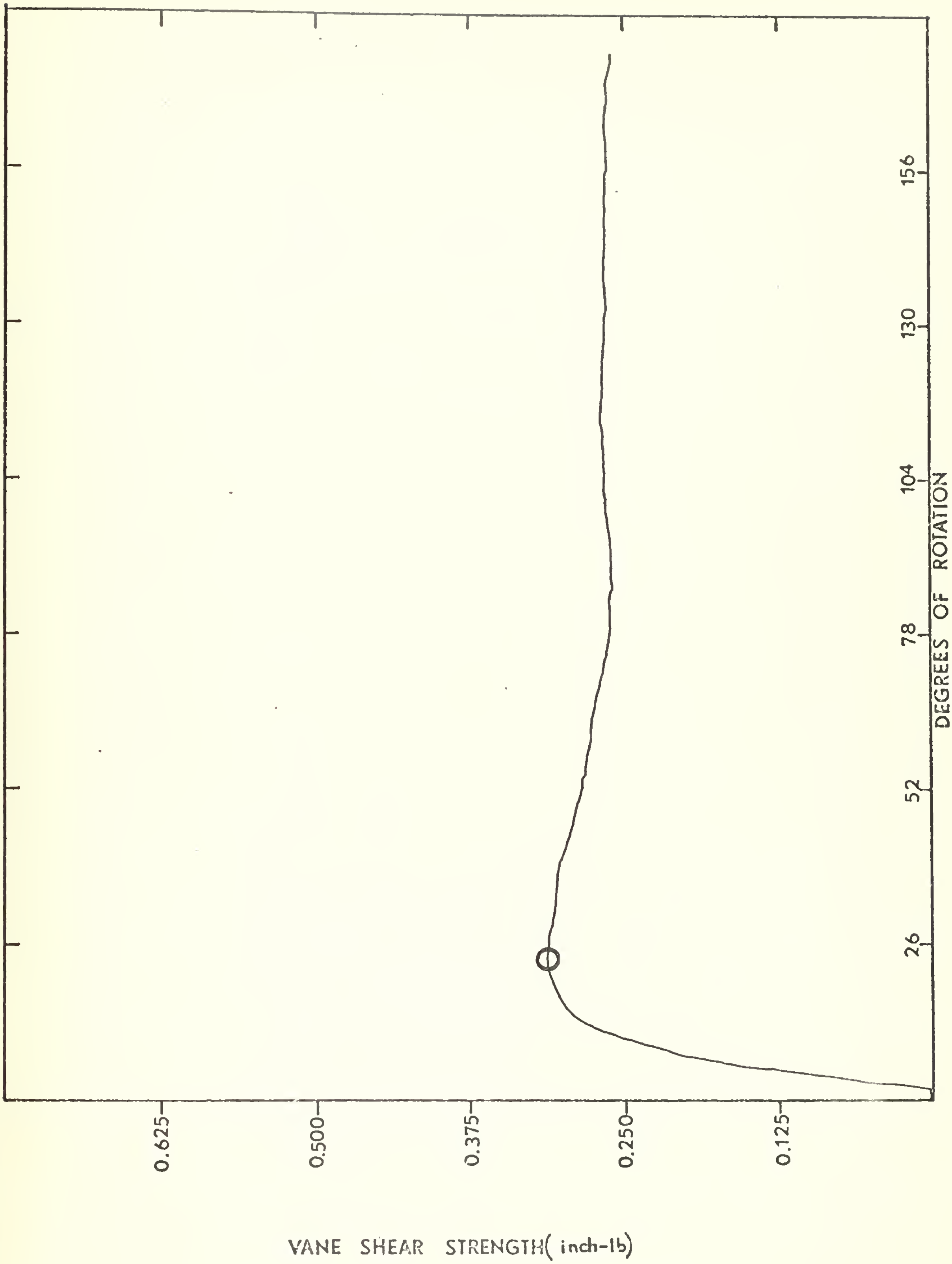

Figure 29. Vane Shear Profile of Section 8 Core 7

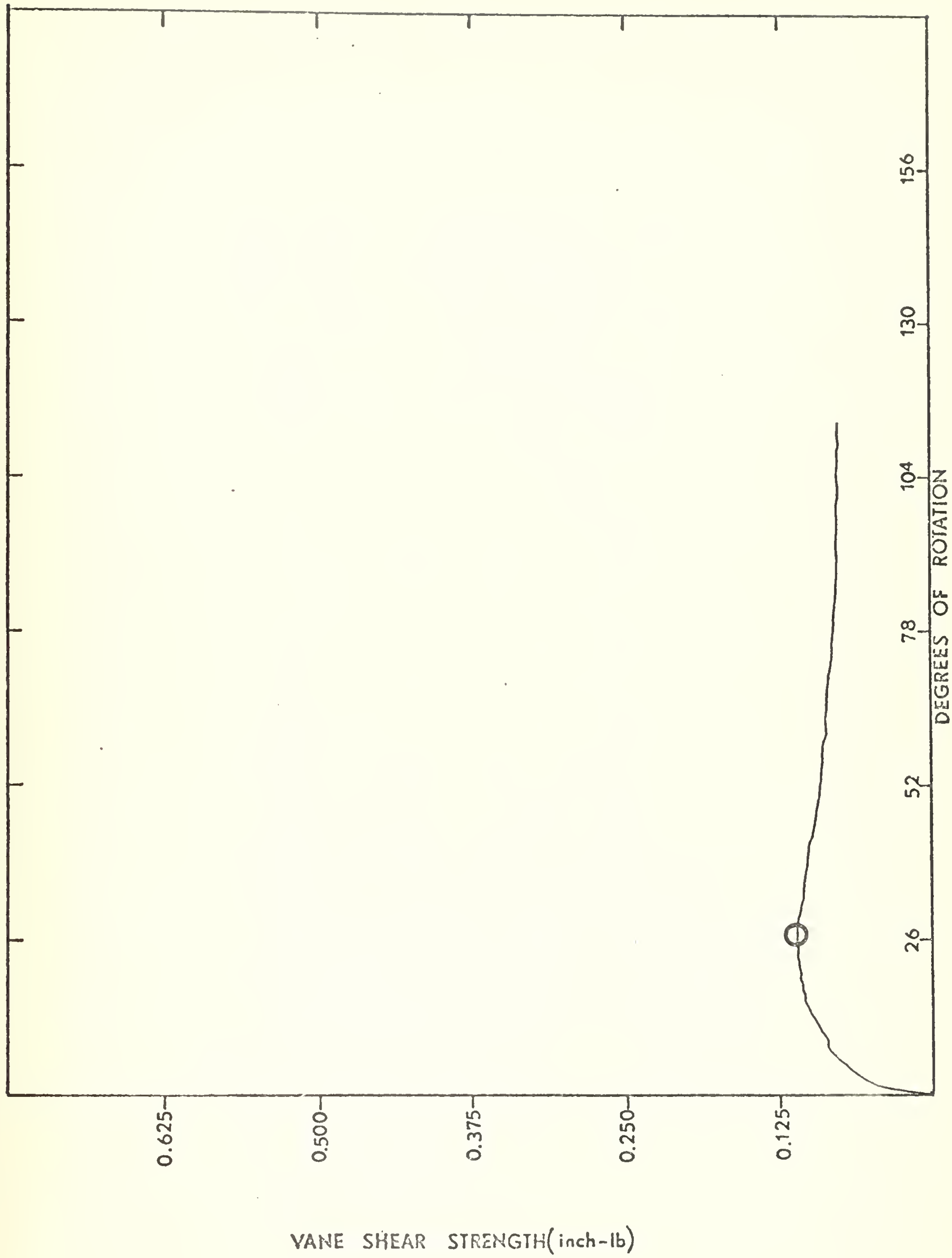

Figure 30. Vane Shear Profile of Section 1 Core 8

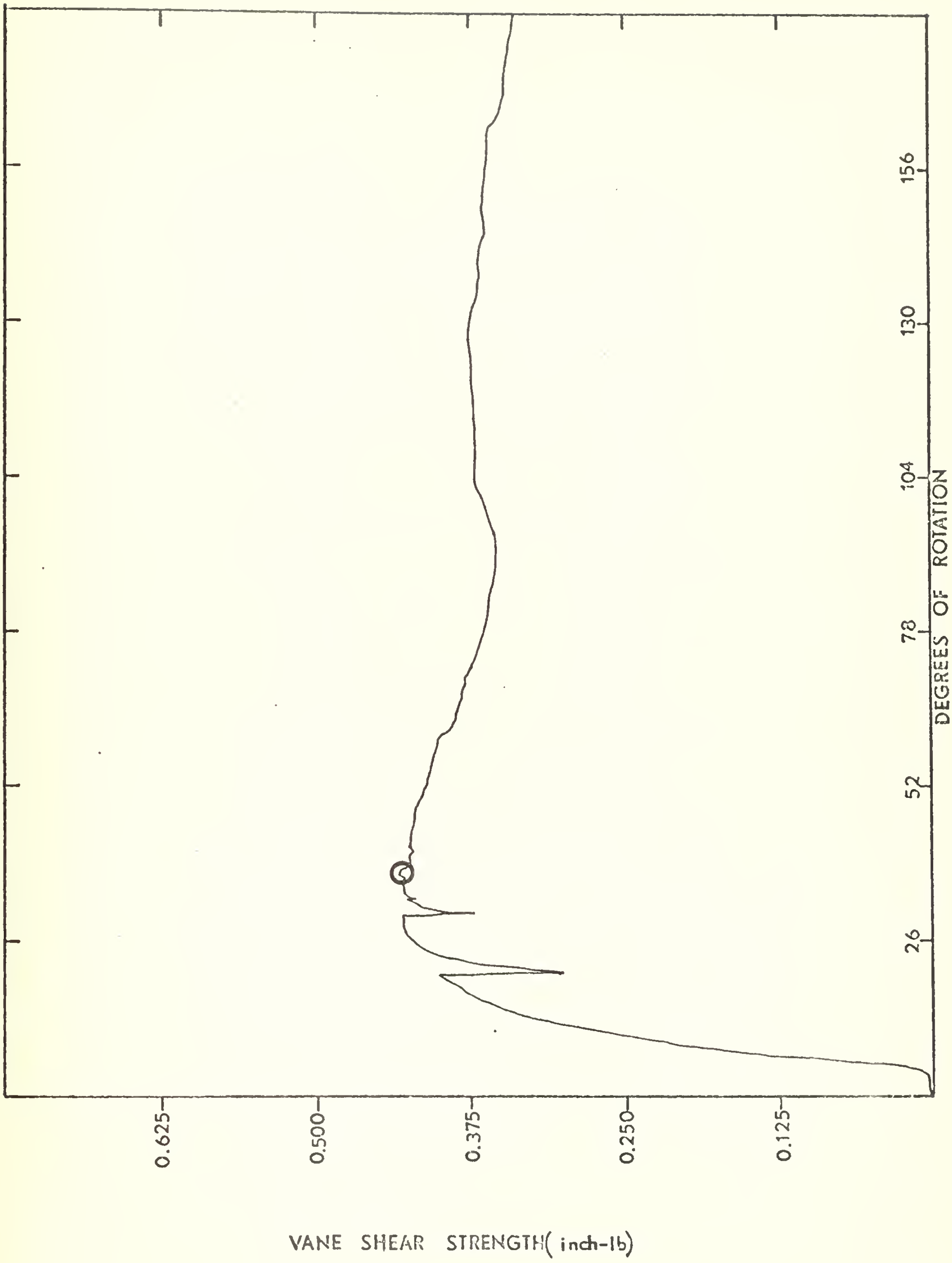

Figure 31. Vane Shear Profile of Section 3 Core 8

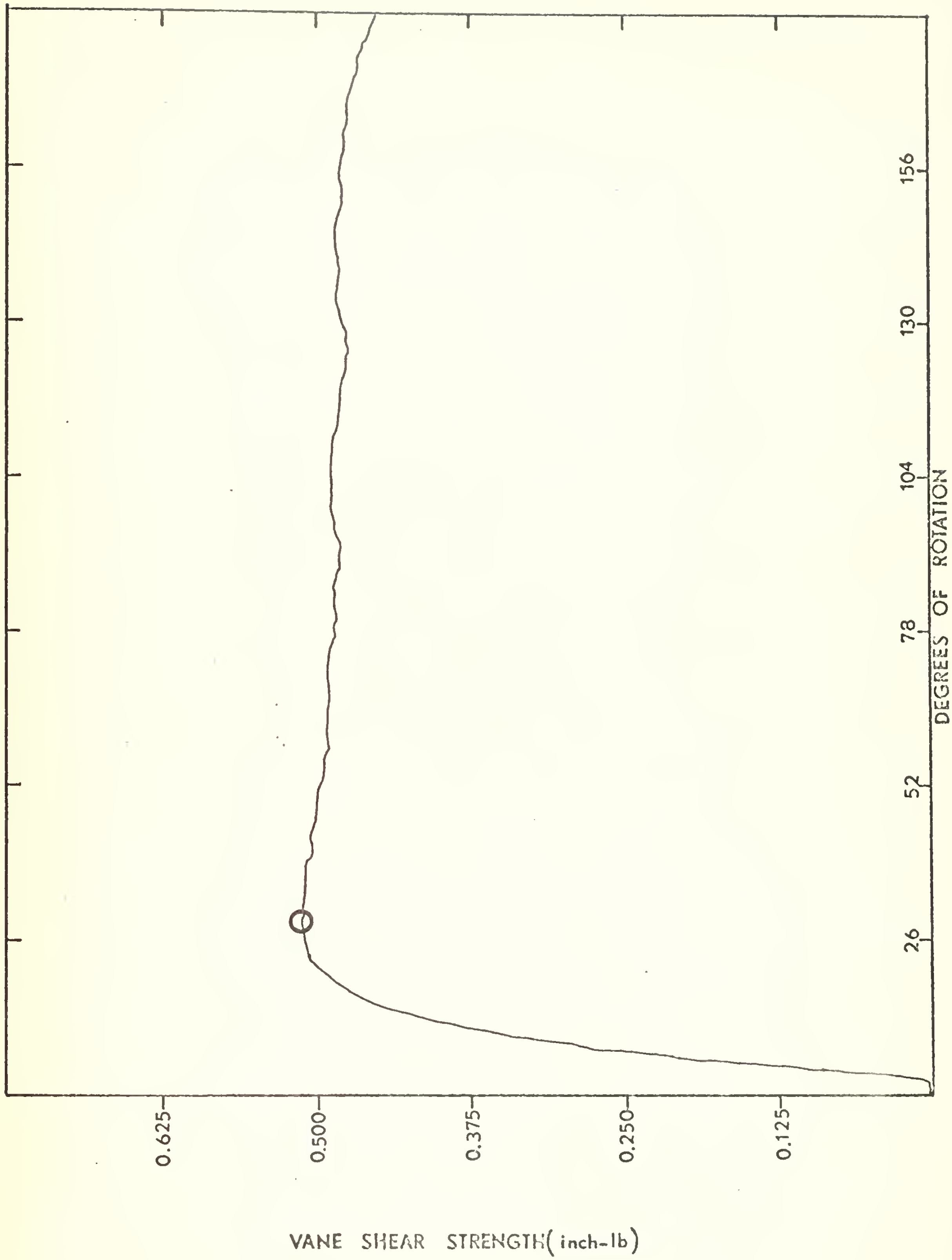

Figure 32. Vane Shear Profile of Section 5 Core 8

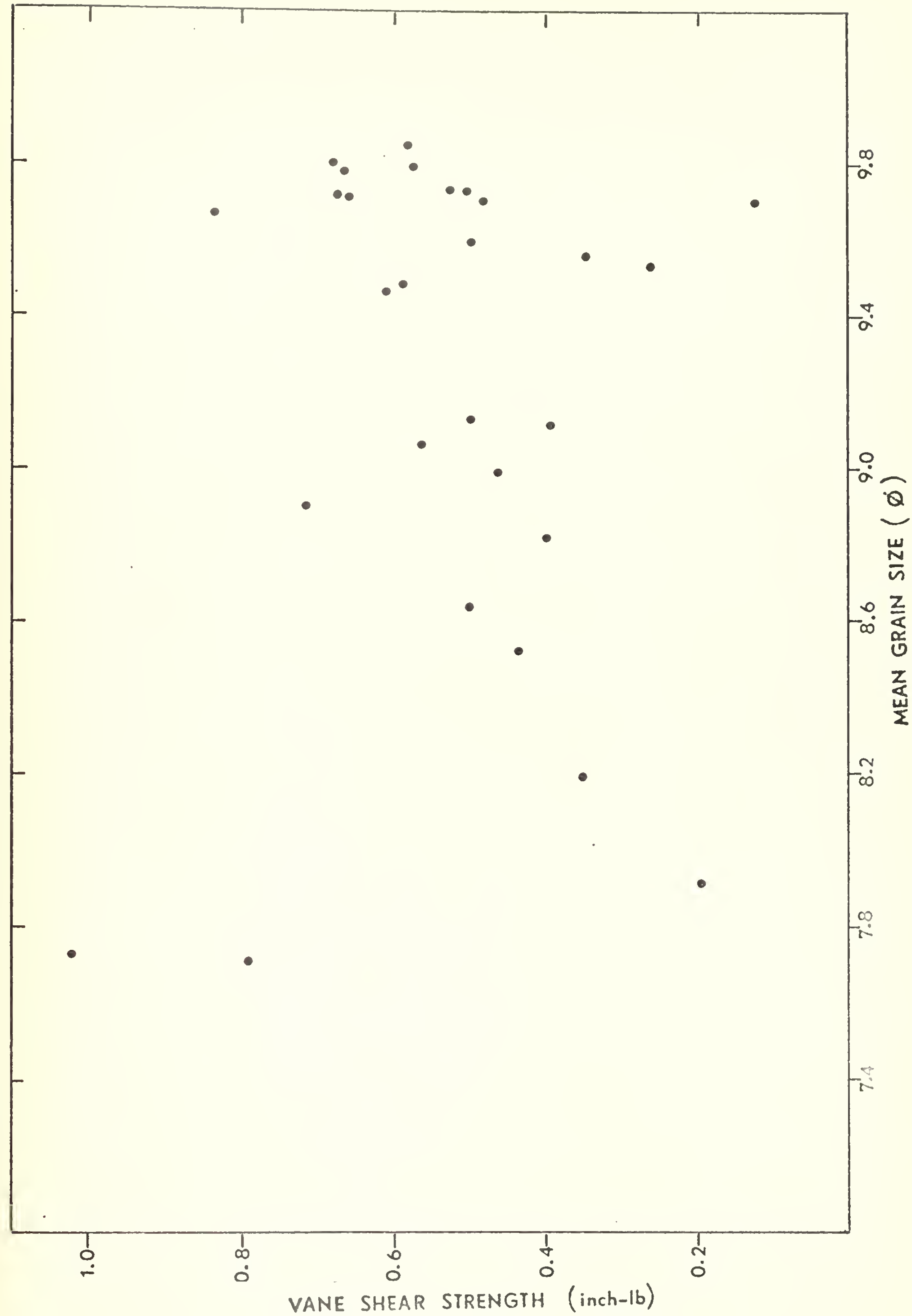

Figure 33. Plot of Vane Shear Strength vs. Mean Grain Size

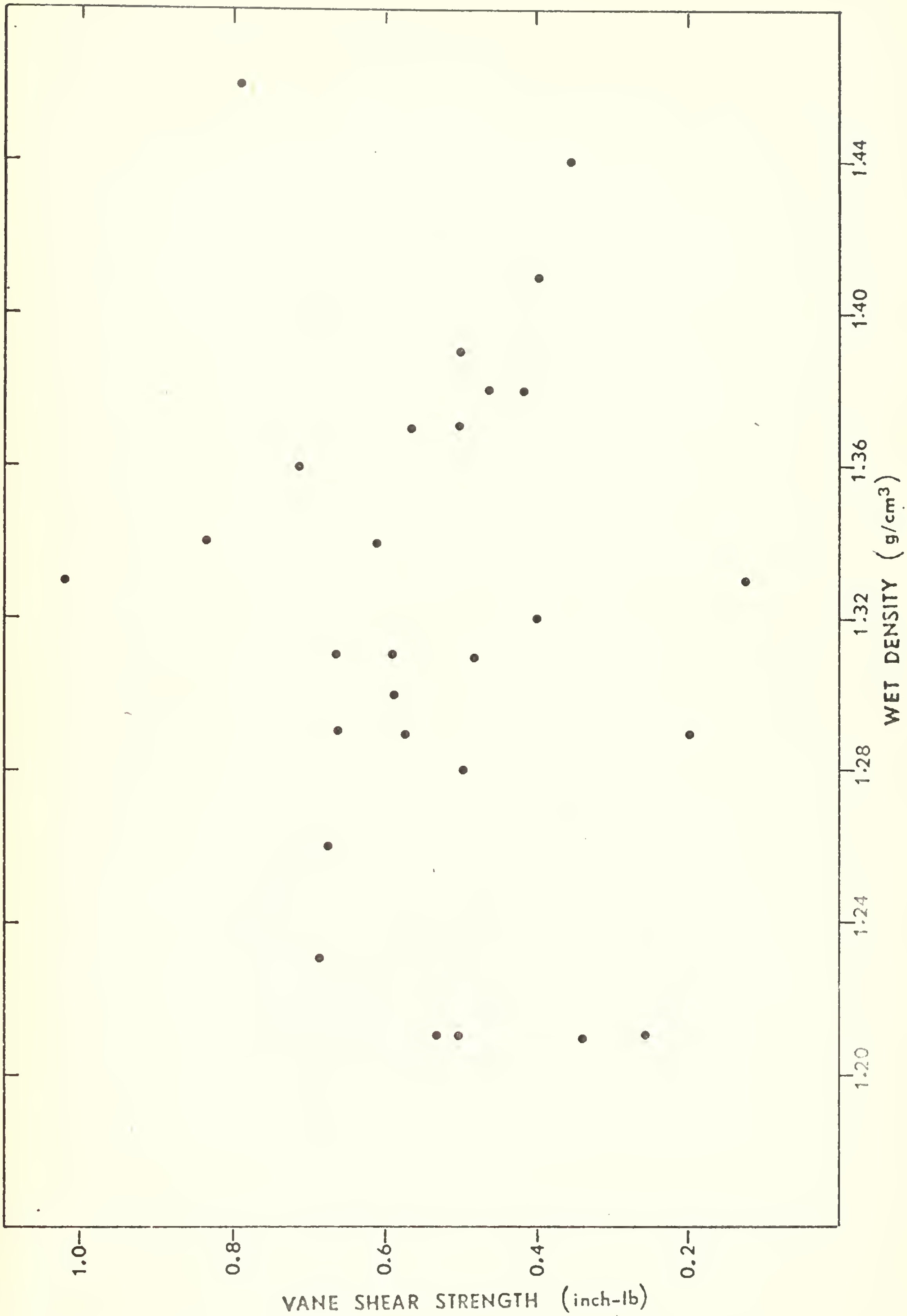

Figure 34. Plot of Vane Shear Strength vs. Wet Density

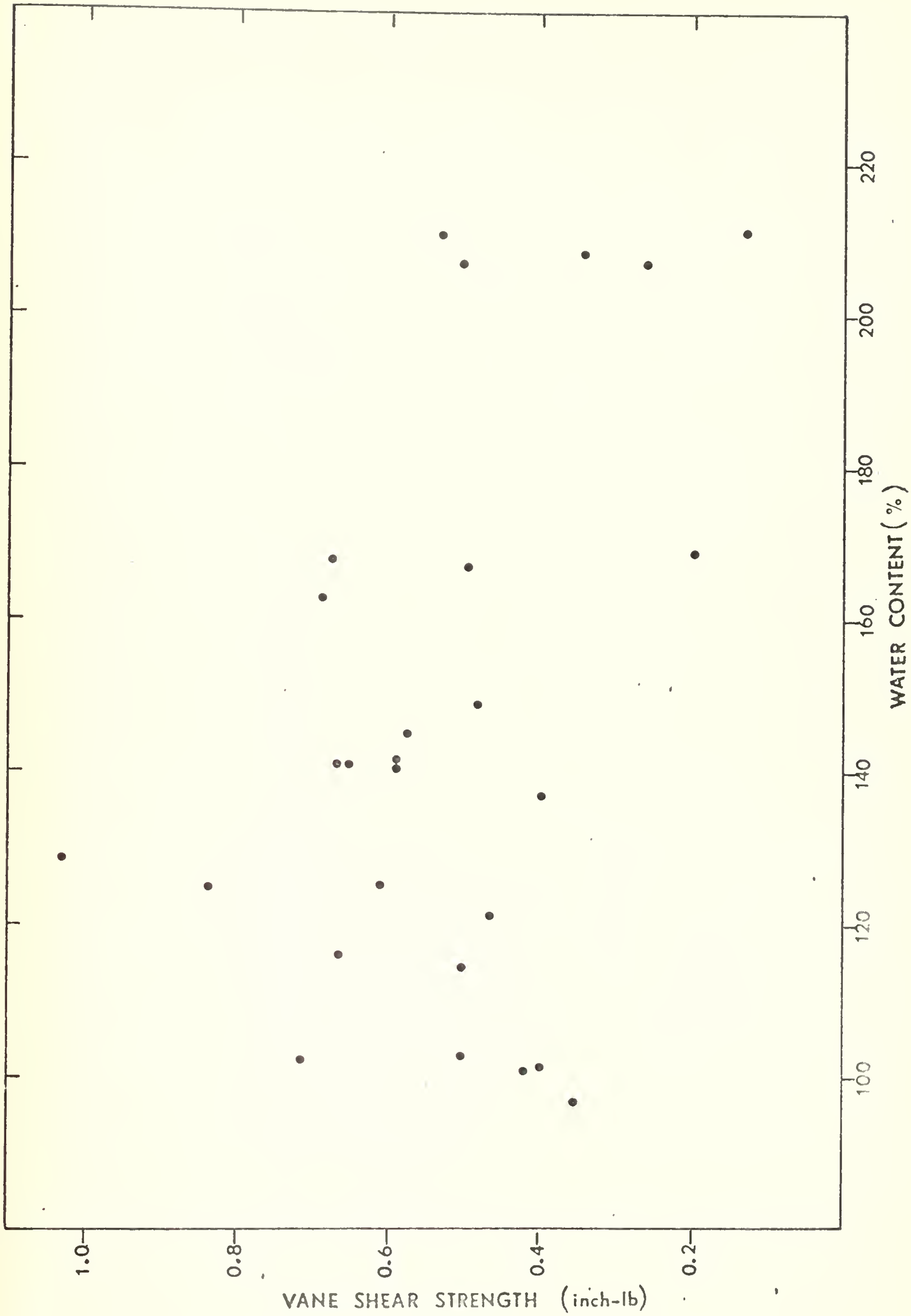

Figure 35. Plot of Vane Shear Strength vs. Water Content

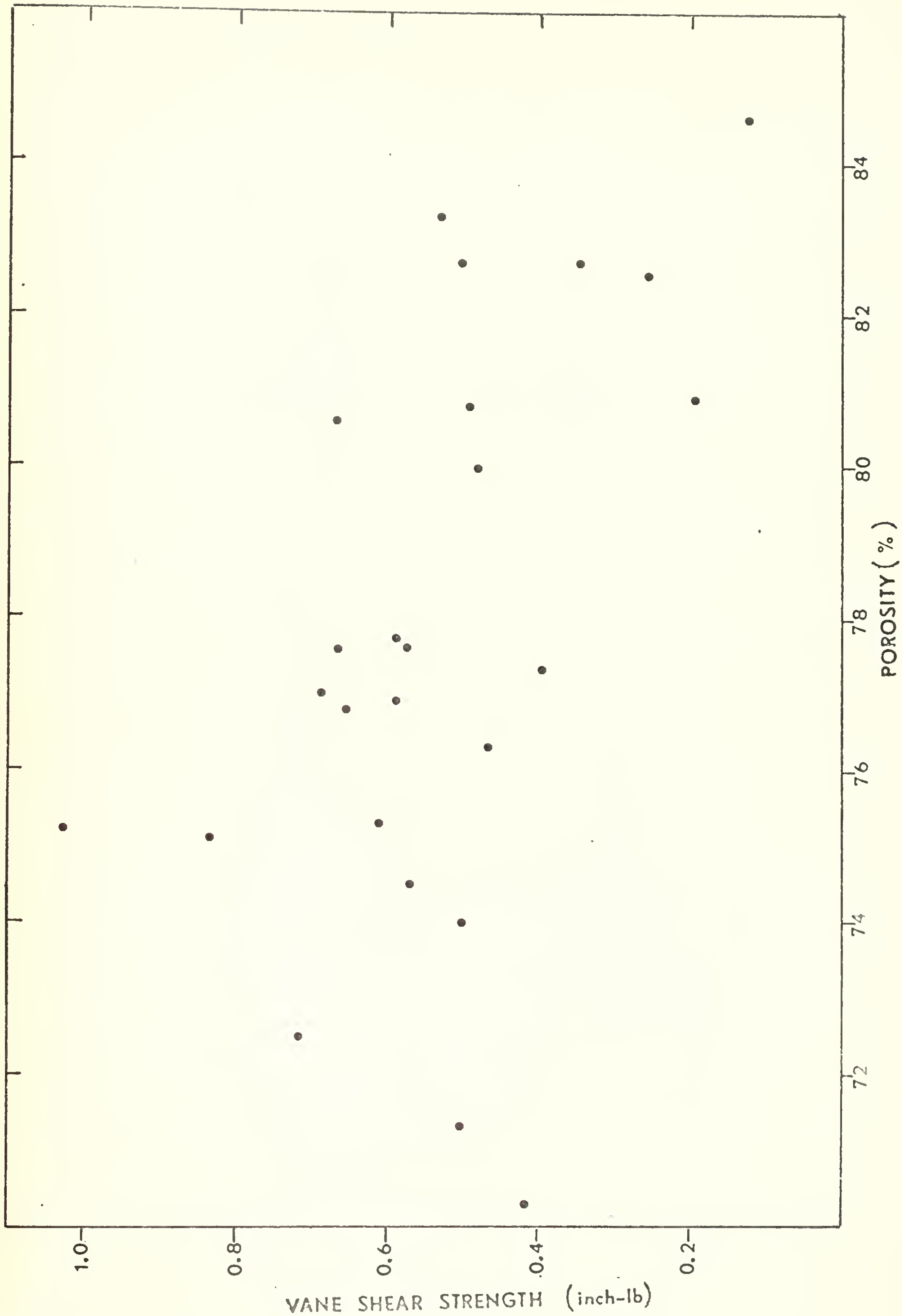

Figure 36. Plot of Vane Shear Strength vs. Porosity

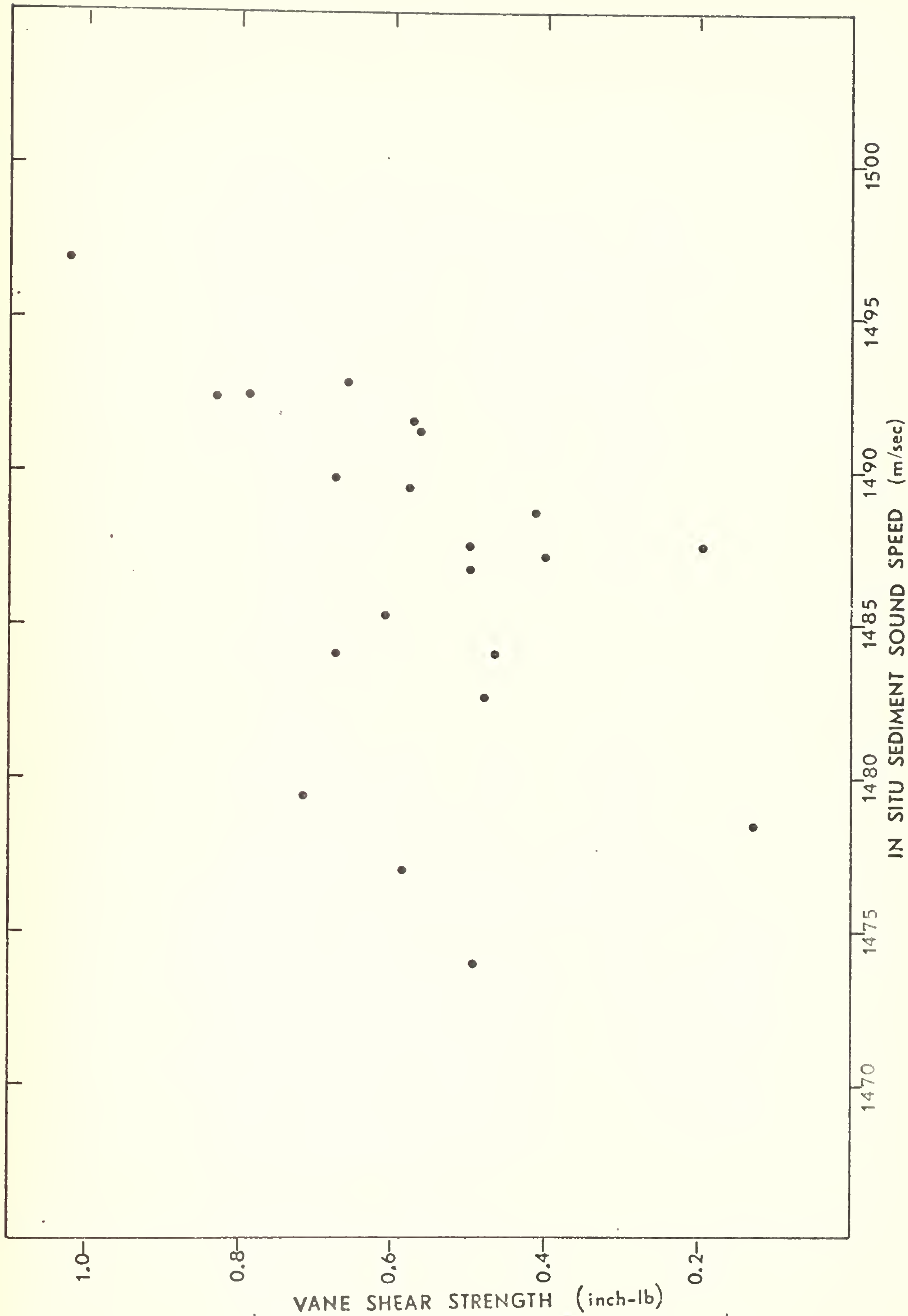

Figure 37. Plot of Vane Shear Strength vs. In Situ Sediment Sound Speed

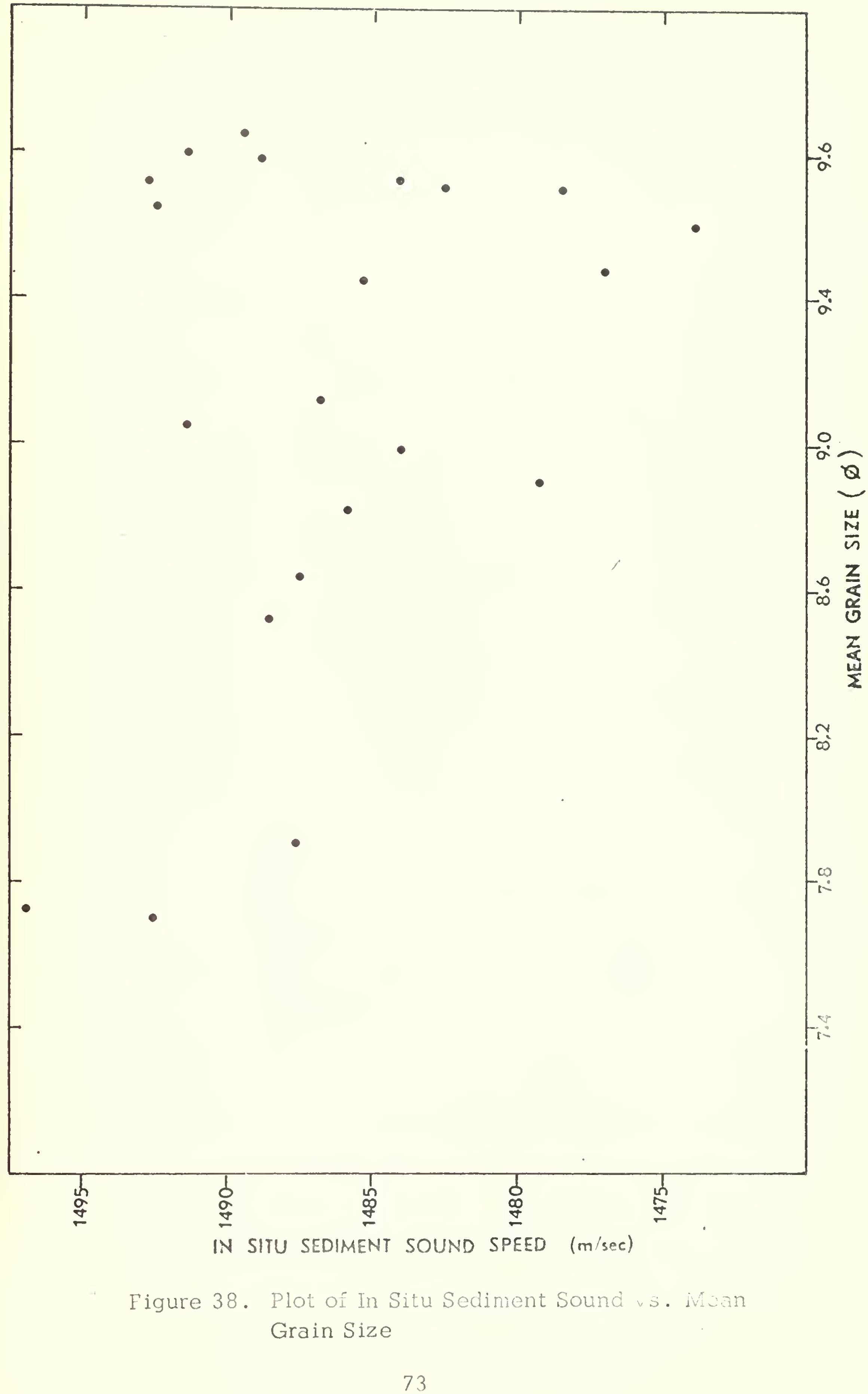

Figure 38. Plot of In Situ Sediment Sound vs. Mean Grain Size

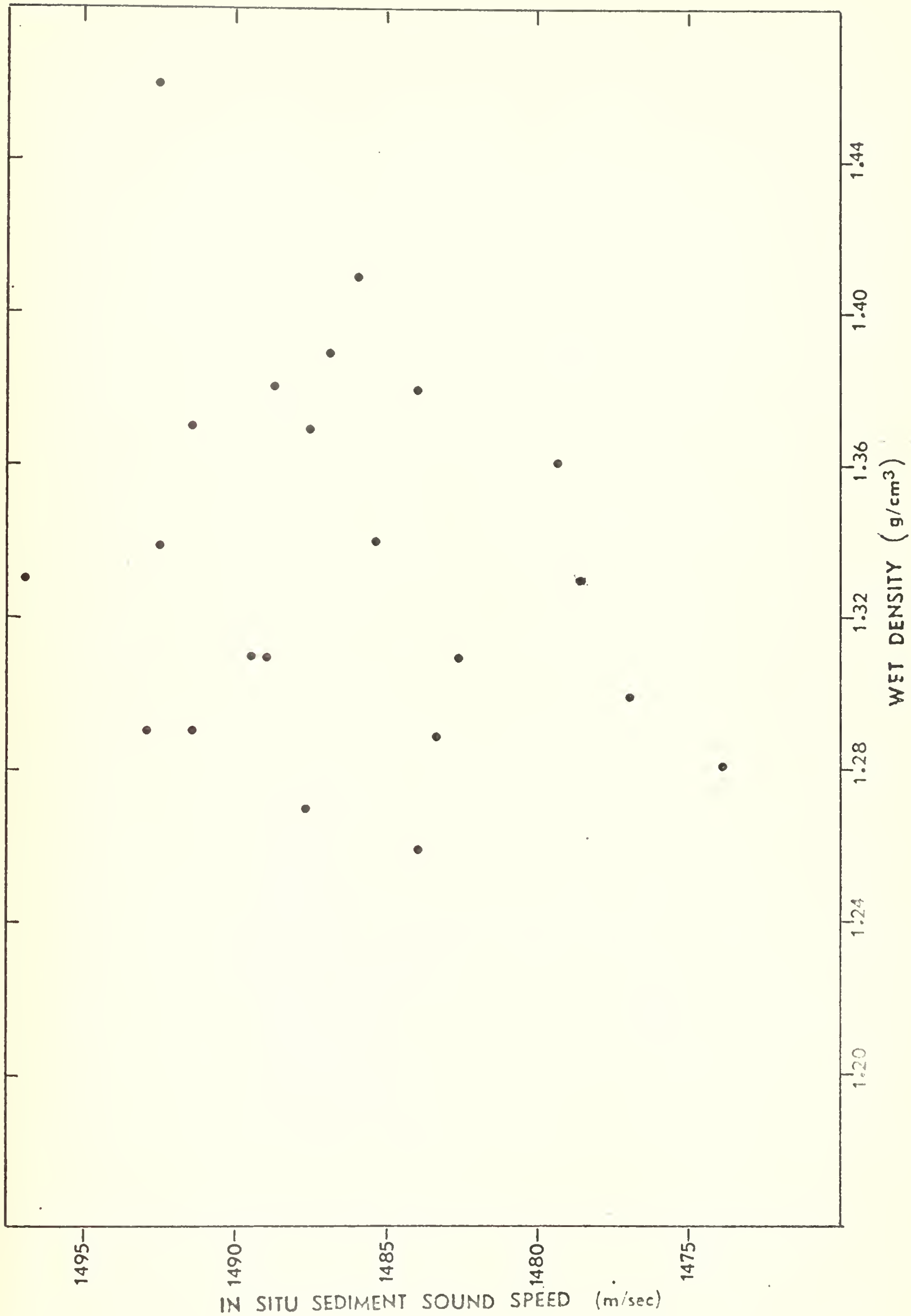

Figure 39. Plot of In Situ Sediment Sound Speed vs. Wet Den

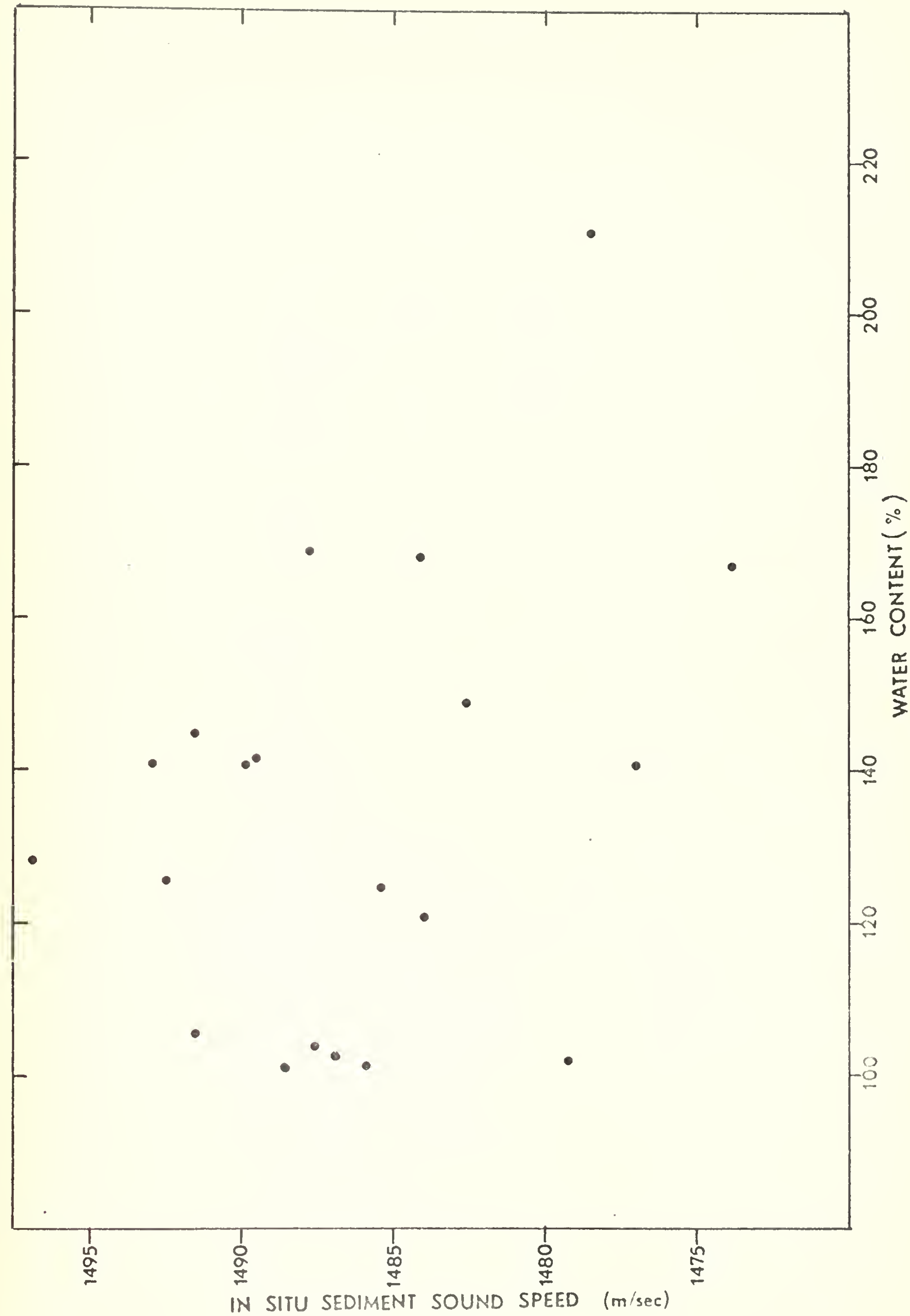

Figure 40. Plot of In Situ Sediment Sound Speed vs. Water Content

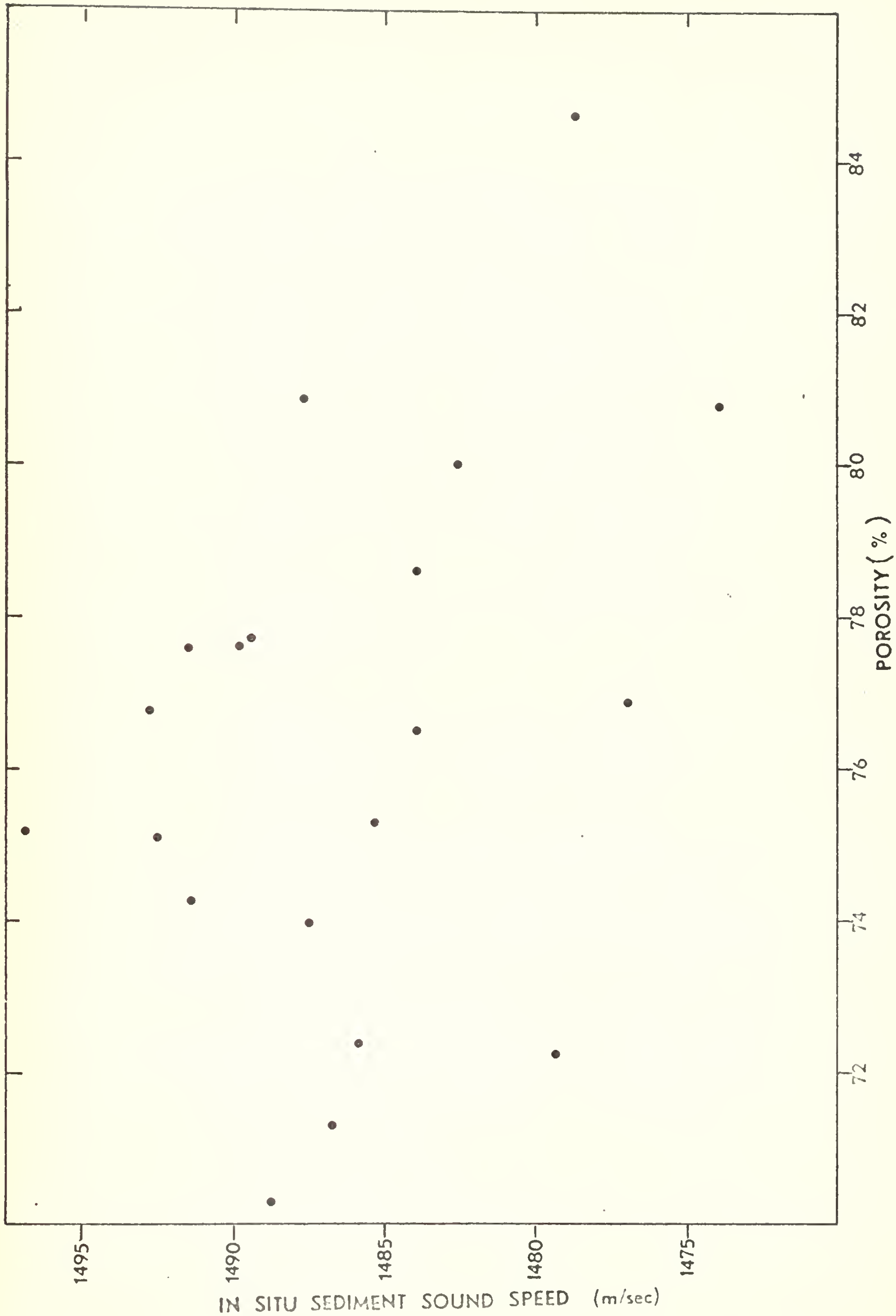

Figure 41. Plot of In Situ Sediment Sound Speed vs. Porosity

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13. ABSTRACT

Eight cores obtained from the Monterey Submarine Fan in the Pacific Ocean 50 to 75 miles off Monterey, California, were sectioned to conduct vane shear, compressional wave speed, and viscoelastic measurements. After the cores were sectioned aboard ship utilizing a heated element technique, core sections were immediately subjected to vane shear measurements utilizing a Wykeham-Farrance Vane Shear Machine modified to produce a graphical display of torque versus angle of blade rotation. Compressional wave speed measurements were also made aboard ship. Wet density, water content, porosity, and grain size distribution of sediment from core sections were determined later in the laboratory.

The relationship of sediment shear strength to mass physical properties and compressional wave speed is discussed. No correlations were apparent between shear strength of the sediment and any single mass physical property or the compressional wave speed of the sediment. A critical discussion of the vane shear test is presented with recommendations for test improvement.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Marine Sediments						
Monterey Submarine Fan						
Vane Shear						
Water Content						
Porosity						
Acoustics						

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